Distribution, trapping efficiencies and feeding trials for *Paranephrops zealandicus* in central Canterbury

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Abstract

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Freshwater crayfish are a taonga species of New Zealand waterways that are highly valued as mahinga kai by many local iwi. Crayfish can also be an important keystone species by acting as bioengineers that create habitats for other species as well as contributing to the maintenance of stream health. My research focused on the native South Island crayfish (Kekewai, *Paranephrops zealandicus*) and was comprised of three components; field surveys to determine the occurrence of crayfish in Canterbury streams, testing of alternative sampling techniques and investigating feeding. Crayfish distribution was patchy throughout the region, with some historic sites having possibly lost crayfish populations. Comparison of active and passive methods for capturing crayfish indicated differences in catch rates and various trapping biases. Electric fishing was the most effective method for capturing kekewai and showed no bias for sex or size. I also compared artificial and natural Māori Tau kōura traps and found that natural traps attracted a higher number of individuals than artificial traps. Feeding trials examined the palatability of various foods including macrophyte species, detritus and invertebrates (i.e. mayflies and snails) as well as investigating food preferences within food groups. Results from these trials confirm that kekewai are opportunistic omnivores and will consume a variety of food items. The results from this thesis can be used to inform management and restoration projects.

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Tēnā e āku manu whitua, e āku manu tātaratiki, naia ngā mihi.

Tēnei tāku manu ka tū ka rere. Mai i te kura i Matariki ki ngā waitapu o Hapuku ko tenei a Te Aitanga-a-Tame e tū nei
Ka rere tāku kāhu korako ki te pīnaki o Te Tapuae-o-Uenuku, ko ōna parihau e tapakō ana kia riro te hā tipua o te awa ko Hāpuku. Ka rere ki tai ki te kōmato o te rangi, e taea te rongorongo te pao o ngā hoe mai i a Tākitimu; ka aue i te tirohanga atu. Ki te uta o tua; tērā te whenua me kī he Mangā-niho-koi-hei-māunu, ko te āhuru mōwai tērā mō Ngāti Kurī me ōna uri whakaheke. kua tapa ko Hōhepa hei ingoa mōna. Ko tēnei te pakiaka ka rato ki ahau te tū nei, ko ōku tūpuna te ahikāroa e.
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I tū; ko, ko, ko, i tū hā ē!

Ko Te Tapuae-o-Uenuku te maunga.
Ko Hāpuku me Te Waiautoa ngā awa.
Ko Tākitimu te waka.
Ko Mangāmāunu te marae
ko Hohepa tōna whare tīpuna
Ko Takahanga te marae.
Ko Maru-kai-tātea tōna whare tīpuna
Ko Ngāti Kurī, ko Ngāti Moruka, ko Ngāi Tūteahuka ngā hapū.
Ko Ngāi Tahu te Iwi

Nōreira e ngā manu kaewa, kia toitū te marae o Tāne, toitū te marae o Tangaroa, toitū te iwi

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General Introduction

1.1 Introduction

Commonly known as crayfish or crawfish, decapod crustaceans in the families Astacidae, Cambaridae, and Parastacidae are native freshwater ecosystem inhabitants on every continent with the exception of Antarctica and Africa (Taylor et al. 1996). Natural populations are also found in some island nations including England, Ireland, Indonesia and New Zealand (Holdich and Reeve 1991, Sibley et al. 2002, McDowall 2005, Lukhaup and Pekny 2006). The three families of freshwater crayfish are taxonomically organised into two superfamilies, Astacoidea which also incorporates Cambaridae in the Northern Hemisphere and Parastacidae in the Southern Hemisphere (Crandall and Buhay 2008). Globally, there were more than 540 recognised and described crayfish species in 2002 (Holdich and Crandall 2002), however, by 2008 this number had increased to 640 described species of crayfish with more being discovered each year (Crandall and Buhay 2008).

Although there are a number of crayfish species, many of these are threatened or endangered in their natural habitats. It is estimated that more than one third of the world's crayfish species are endangered and are considered to be either declining in numbers or at risk of extinction (Scalici et al. 2008). As many crayfish species have yet to be categorised for conservation status relative to the International Union for the Conservation of Nature (IUCN) Red List Criteria, this estimate is most likely conservative (Crandall and Buhay 2008).

Ecological role of crayfish

For many species, success and persistence relies heavily on resource partitioning and establishing and maintaining a niche within a community assemblage. Species that co-exist and rely upon the same resources for survival are subject to strong interspecific and intraspecific competition pressure (Schoener 1974). As species cannot successfully co-exist for an extended period of time when resources are limited and competition pressure is strong (Schoener 1974), they need to adapt either by becoming specialists and be able to out compete other species for a particular resource, or becoming generalists whereby they can switch to another resource when current resources are depleted or scarce.

Most freshwater crayfish species are opportunistic omnivores with a varied diet that includes invertebrates, macrophytes, biofilm, algae and detritus (Parkyn et al. 1997, Parkyn et al. 2002, Parkyn and Kusabs 2007, Giling et al. 2009). They feed across multiple trophic levels, as predators, herbivores and detritivores, therefore, their actions can have a profound effect on nutrient cycling and in-stream processes (Giling et al. 2009). Crayfish play an important role in stream food webs. They increase the availability of organic matter and nutrients to other organisms by processing vegetation and leaf litter (Huryn and Wallace 1987, Griffith et al. 1994, Taylor et al. 1996). Crayfish are also an important food source for birds, eels and fishes (Parkyn et al. 2002, Giling et al. 2009, Tablado et al. 2010).

Crayfish are bioengineers, not only do they influence community composition but they also affect the physical environment (Creed and Reed 2004, Giling et al. 2009). In common with other large stream biota that influence sediment distribution, crayfish also possibly contribute significantly to developing and shaping benthic substrata (Zhang et al. 2004, Giling et al. 2009). A study conducted by Zhang et al (2004) in the Coast Range Mountains, BC, Canada, found that dramatic changes in ecosystem and community attributes had occurred as a result of crayfish removal.

The lifespan of most crayfish species is 2 – 3 years, with the exception of a few species that can live for several decades (Taylor et al. 1996, Crandall and Buhay 2008). Crayfish reproduce sexually and mating usually occurs around autumn through to early winter (Taylor et al. 1996, Larson and Magoulick 2008). Eggs from fertilised females are extruded and carried under the abdomen in spring (Taylor et al. 1996, Larson and Magoulick 2008). Once extruded, hatching can occur within a few days to weeks (Taylor et al. 1996). Shortly after hatching, juvenile crayfish leave the female and fend for themselves (Taylor et al. 1996).

Crayfish in New Zealand

New Zealand has two extant crayfish species. From the family Parastacidae, *Paranephrops planifrons* and *P. zealandicus* are endemic. The distribution of the two species is well defined, with no areas identifying as having both species present. *P.planifrons* is found throughout the North Island and down to the top and west of the South Island, and *P. zealandicus* is found along the east and south of the South Island as well as Stewart Island

(Figure 1.1). However, recent findings have indicated that the New Zealand populations may be made up of several or more distinct sub-species (NIWA, pers.coms).

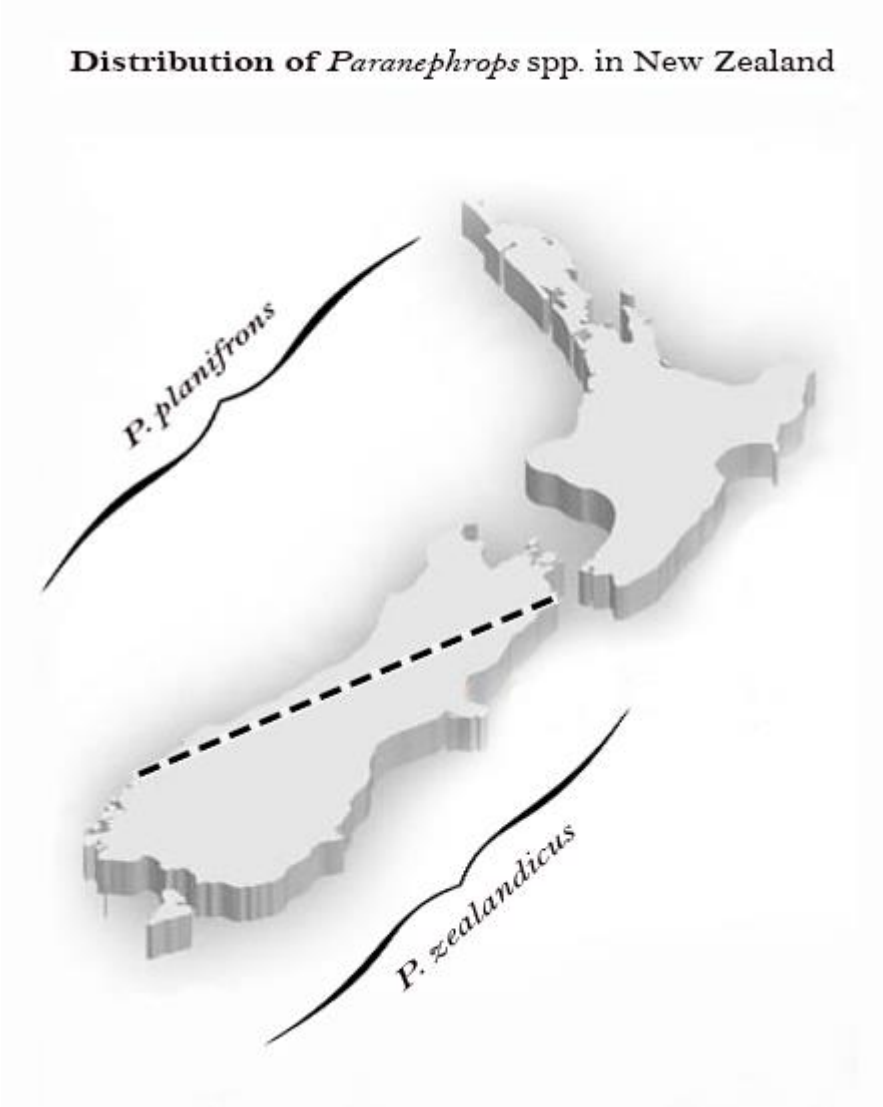

Figure 1.1 Conceptual map showing the distinct change in distribution for the two extant *Paranephrops* species.

Ecological role

The ecological role of New Zealand freshwater crayfish is unusual. They are New Zealand's only freshwater omnivores. As New Zealand has no native herbivorous fishes, they are potentially the only freshwater animal that could potentially aid in controlling invasive macrophytes. Crayfish also play a major role in New Zealand aquatic ecosystems as bioengineers that affect debris sedimentation and accumulation of organic matter (Parkyn et al. 1997, Usio and Townsend 2001). These processes help shape the physical environment as well as providing resources and creating habitats for other aquatic fauna. Crayfish also

influence benthic invertebrate communities either indirectly by processing organic matter or through bioturbation or directly by predation (Parkyn et al. 1997).

Crayfish play an important role in New Zealand freshwater food webs (Usio and Townsend 2002). Not only do they process matter for other benthic invertebrates, but they are also an important food source for native fishes (Hicks 1997, Parkyn et al. 2002). Native aquatic birds such as shags and possibly blue ducks are also known to feed on crayfish (Dickinson 1951, Collier 1991). Unfortunately, predation by introduced species such as trout (*Salmo trutta*), has had an impact on crayfish populations (Townsend 1996). McDowall (1968) found it difficult to detect crayfish in streams populated by adult trout. Other studies have also found negative associations between trout introductions and crayfish distribution (Usio and Townsend 2001). Although kekewai do modify their behaviour in the presence of both native and introduced predators, they tend to show more anti-predator behaviour when exposed to chemical cues from native predators than they do from exotic predators (Shave et al. 1994). This has been attributed to co-evolutionary adaptations.

Paranephrops spp. and in particular *P. zealandicus* can achieve potentially long lifespans, with some individuals reaching in excess of twenty years (Devcich 1979, Whitmore 1997). After mating, *P. planifrons* females can be gravid for around 25 weeks (Hopkins 1967). In contrast, *P. zealandicus* can be gravid for up to 60 weeks (Whitmore 1997). Therefore, there are potential reproduction limitations for kekewai species.

Diet of Paranephrops spp.

The diet of New Zealand crayfish consists primarily of detritus (Whitmore 1997). However, it has been shown that more mature specimens prefer vegetative organic matter whereas smaller, juvenile crayfish are more inclined to prey on invertebrates (Parkyn et al. 2001, Hollows et al. 2002). A study examining dietary requirements of *P. zealandicus* revealed that vegetative matter was the most dominant food found in stomach contents, whilst invertebrate prey constituted less than four percent (Hollows et al. 2002). However, stable isotope analysis indicated that invertebrate prey greatly contributed to crayfish biomass (Hollows et al. 2002). The difference between stomach content volume and stable isotope analysis could be because invertebrate soft tissue is easier to digest than detritus or vegetative matter and readily assimilated into overall crayfish biomass (Hollows et al. 2002). Another study conducted by Parkyn et al. (2001) showed that gut contents analysis of crayfish in native forested streams was comprised of >60% of leaf detritus. In contrast, gut analysis of crayfish in pasture streams showed <30% detritus composition (Parkyn et al. 2001).

However, stable isotope analysis of crayfish tissue revealed that energy from invertebrate prey was assimilated but that detritus energy was not used for growth (Parkyn et al. 2001). These findings agree with those of Hollows et al. (2002). As there is little literature on macrophyte consumption, it is unknown if New Zealand crayfish do or could incorporate this into their diets.

Habitat preferences

Crayfish prefer shaded habitats, and will seek cover during the day in stream environments (Parkyn and Kusabs 2007). In deeper waters, they will travel upwards at night to feed in the shallow water zone (Parkyn and Kusabs 2007). They have also been known to forage onto bare mud flats, but quickly retreat into macrophyte or riparian growth when disturbed (Parkyn and Kusabs 2007). The natural habitat for crayfish in native forest streams consists predominantly of cover such as fallen logs, leaf litter deposits, tree roots and undercut edges (Parkyn and Kusabs 2007, Jowett et al. 2008). Woodless reaches and pastoral streams with undercut edges can also provide suitable habitat cover for crayfish (Hicks and McCaughan 1997, Jowett et al. 2008), however wood within the aquatic environment increases the stream area used as a habitat by providing surrogate edge habitats (Parkyn et al. 2009). Hicks and McCaughan (1997) showed that there was no significant difference for crayfish abundance between native forests, exotic forests or pastoral land use types. However, they advised caution for their crayfish density estimates because sites were selected for fish capture and may not have been entirely suitable for crayfish capture (Hicks and McCaughan 1997).

Nomenclature

New Zealand crayfish are generically referred to as kōura, which also includes the native marine spiny rock lobsters *Jasus edwardsii,* however the term wai kōura has also been used to describe freshwater crayfish. In Canterbury, the local indigenous peoples refer to the freshwater crayfish *P. zealandicus* as kekewai, which distinguishes them from their marine counterparts. I was first made aware of this terminology in communications with Te Marino Lennihan, a kaitiaki (guardian/steward) of Tūāhuriri, the name kekewai was also used by Craig Pauling of Taumutu, therefore, out of respect for tāngata whenua (people of the land) for the area where I am conducting most of my research I have decided to use this name when referring to *P. zealandicus* my study. As settlements of Southern tribes were predominantly coastal, both marine and freshwater crayfish were important mahinga kai species, that is,

traditional food species, therefore, it seems reasonable that this distinction would be important.

Cultural significance

Kekewai or wai kōura are a tāonga (highly valued) species for Māori. They are an important mahinga kai (traditional subsistence food) species for many iwi (tribes). For Māori, food resources are highly valued and are an integral part of tribal economy. In addition to this, the ability to feed manuhiri (guests) on the bounty that is provided by the rohe (area) reflects not only the mana of the iwi, but also reflects the foresight in the choices of their tīpuna (ancestors).

Crayfish are harvested from many freshwater streams and waterways throughout New Zealand and the lakes of Te Arawa and Taupo are considered to be among the most productive (Parkyn and Kusabs 2007). Māori still harvest from these lakes using traditional trapping methods today. There are a variety of traditional techniques and methods employed to harvest crayfish including tāu-koura. This technique uses bundles of bracken fern (*Pteridium esculentum)* traditionally called whakaweku, which are then placed at the bottom of a lake or stream for crayfish to colonise (Parkyn and Kusabs 2007, Kusabs and Quinn 2009). The tāu-koura remains submerged for at least one month before it is retrieved and the crayfish are harvested. Females in berry with eggs or young are not taken for consumption, but are released back into the water (Parkyn and Kusabs 2007).

1.2 Research objectives

Rationale and aims for this study

The main objectives of this thesis were to determine current distribution of kekewai populations around central Canterbury (Chapter 2), to compare efficiencies of different capture techniques and trapping methods (Chapter 3) and to investigate palatability and preferences of different foods types (Chapter 4).

There is very little literature documenting the current distribution of *P. zealandicus* in central Canterbury. Although there are some historical documented accounts of crayfish distribution in Chilton (1888) and Chilton (1899) throughout central Canterbury, most of what is known comes from anecdotal evidence. The New Zealand Freshwater Fish Database (NZFFD) was primarily intended for fish information, however, there were some recorded historical occurrences of crayfish. My aim was to map the current distribution of *P. zealandicus* in central Canterbury.

There are many methods that can be used to capture crayfish, however, there are often associated biases for some techniques. In addition some methods and techniques may not be suitable for different water body types. I compared the efficiencies of different trapping methods and capture techniques to determine which are best suited for sampling and monitoring current kekewai populations.

The diets of *Paranephrops* spp. have been well documented in terms of detritus and invertebrate prey, however there is little known about macrophyte consumption. Much of what is known about kekewai diets comes from field studies and gut content analysis. I conducted laboratory experiments to determine palatability of different food types as well as choice experiments to see if kekewai showed preference for different foods offered. I also wanted to determine what effects body size had on predation.

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Distribution of freshwater crayfish (*Paranephrops zealandicus*) in Central Canterbury

2.1 Introduction

Globally, freshwater fauna are at risk with many species endangered or threatened with extinction (Ricciardi and Rasmussen 1999, Dudgeon et al. 2006). It has been predicted that the future mean rate of decline for freshwater fauna will be more than five times that of terrestrial fauna and three times that of marine mammals (Ricciardi and Rasmussen 1999). Freshwater crayfish are among those species that are at high risk with more than a third of the species regarded as endangered or threatened (Scalici et al. 2008). Although many crayfish species appear on the IUCN Red List, there are many that have yet to be categorised for conservation status (Crandall and Buhay 2008). It is consequently likely that the estimate by Scalici et al. (2008) is highly conservative.

This global rate of decline highlights the urgent need for distribution and census surveys as well as effective monitoring of existing crayfish populations. Comparing historical distribution patterns to current population distributions will allow for an accurate assessment of how populations are coping in a changing environment. Information that is gathered from these censuses could then be used to inform effective management strategies.

Surveying crayfish distributions often incorporates a variety of methods and techniques for both historical and current population census. These can include historical mapping and documentation, literature reviews, interrogation of museum and zoological collections as well as accumulating anecdotal evidence (Salvidio et al. 1993, Taylor et al. 1996, Sibley et al. 2002, Maguire and Gottstein-Matočec 2004). As crayfish can be native or invasive inhabitants in a variety of freshwater ecosystems, distribution surveying need to be conducted in different habitat types such as lakes, ponds, streams, water races/pasture drains, caves and other terrestrial and subterranean riverine systems (Camougis and Hichar 1959, Holdich 2002, Holdich and Crandall 2002). The accessibility and water body type can heavily influence the techniques and methods that can be implemented (Holdich and Reeve 1991). Therefore, when surveying the current distribution it is important to use the appropriate methods for the water body type that will ensure effective sampling. These can include active sampling techniques, for example spotlighting, hand capture, netting and

electric fishing or passive methods such as net-trapping or sometimes a combination of methods is more suited (Holdich and Reeve 1991, Rabeni et al. 1997, Acosta and Perry 2000, Alonso 2001).

Current state of Paranephrops in New Zealand

Only a single crayfish genera *Paranephrops*, is endemic to New Zealand, it has two species *P. planifrons and P. zealandicus. P. planifrons* is found in the North Island and the top and west of the South Island and *P. zealandicus* is found only in the South Island and Stewart Island. Local Māori names for these crayfish species include kōura, wai kōura and kekewai (Chapter 1).

The distribution and abundance of kekewai (*P. zealandicus*), in the Canterbury region is unknown. McDowall (2005) stated that crayfish were not known north of Banks Peninsula up to the Waipara River. He theorised that this absence could be attributed to a number of factors including agricultural land productivity and management requiring the use of fertilisers and pesticides, land use change requiring extensive wetland drainage and introduction of predatory salmonid fishes (McDowall 2005). He also suggested that distribution scarcity of kekewai in Canterbury could also be a natural phenomenon and may be the result of low dispersal and recruitment across the plains.

In contrast to McDowall's findings, anecdotal evidence suggests that kekewai populations were more prolific than historical records had indicated. Although McDowall did state data used to determine freshwater crayfish distributions was sourced from the New Zealand Freshwater Fish Database (NZFFD—McDowall & Richardson 1983) in McDowall (2005), it appears that data from other agencies such as Aquatic Ecology Limited (AEL) had not yet been included. This could explain why some of the sites where kekewai were recorded as present were not included in McDowall (2005).

Prior to 1883, it was thought that *P. planifrons* was confined to the North Island and *P. zealandicus* was only present in the South Island, with the reason for this separation of the species being attributed to Cook Strait (Chilton 1888). However, in August 1883, Chilton was able to examine a specimen that had originated from the Matai stream in Nelson. Further investigation led Chilton to determine that distribution of *P. planifrons* extended from Nelson down the west side of the South Island to Greymouth, and that *P. zealandicus* distribution

extended along the east side and across the bottom of the South Island as well as incorporating the Stewart Island.

Historical accounts show that kekewai were present in rivers as well as in smaller tributaries (Chilton 1888). There have been documented accounts of kekewai being captured from both the Avon and Waimakariri Rivers (Chilton 1888) as well as in the Heathcote River (Chilton 1899). Smaller tributaries around Rangiora were also recorded as having kekewai populations (Chilton 1899).

These historic records of kekewai distribution are supported by anecdotal indigenous accounts that refer to kekewai as once being abundant throughout the Central Canterbury region. Kekewai were still present in streams (Dudley Creek) and waterways around Bishopdale and Papanui as recently as the late 1960's through to the early 1970's (L. de Groot, pers. coms 2015) and people that use to frequent Marshlands area have also stated that kekewai were present in waterways around the 1970's (A. Blokker, pers. coms 2015). Kekewai were also known to be abundant around Hilmorton (A. Blokker, pers. coms 2015). Kekewai were abundant in these areas and were often found under rocks or in crevices and burrows in stream banks (L. de Groot., A. Blokker, pers. coms 2015). In 1980, Kekewai were recorded in Wairarapa Stream at two sites, and Ballantines Drain but not in Dudley Creek (Robb 1980).

Research aims

The aims of this research were to investigate kekewai distribution around central Canterbury and to identify physico-chemical factors which might affect kekewai occurrence, recruitment or current populations. I also compared historic and current distributions to determine if there have been any major changes over time. I hypothesised that increases in land development would have negatively affected kekewai populations due to habitat degradation.

2.2 Methods

Potential sites were located from a number of sources including data from the New Zealand Freshwater Fish Database, (NZFFD) maintained by the National Institute of Water and Atmospheric Research (NIWA). This database is compiled from surveys conducted by NIWA as well as other independent researchers and organisations (Figure 2.1). Other sources of information include personal communications from local iwi (tribal) representatives from

both Tuahiwi and Taumutu rohe and anecdotal evidence from previous and current residents as well as people involved within the local communities.

Sites where kekewai had previously been detected on the NZFFD were prioritised with the most recent confirmed detections being investigated first followed by older sightings. Sites that had previously been surveyed but where kekewai had not been detected were investigated last. Google earth was used to do an initial search and overview of these sites and to assess if other waterways on route to the sites could be potential kekewai habitats.

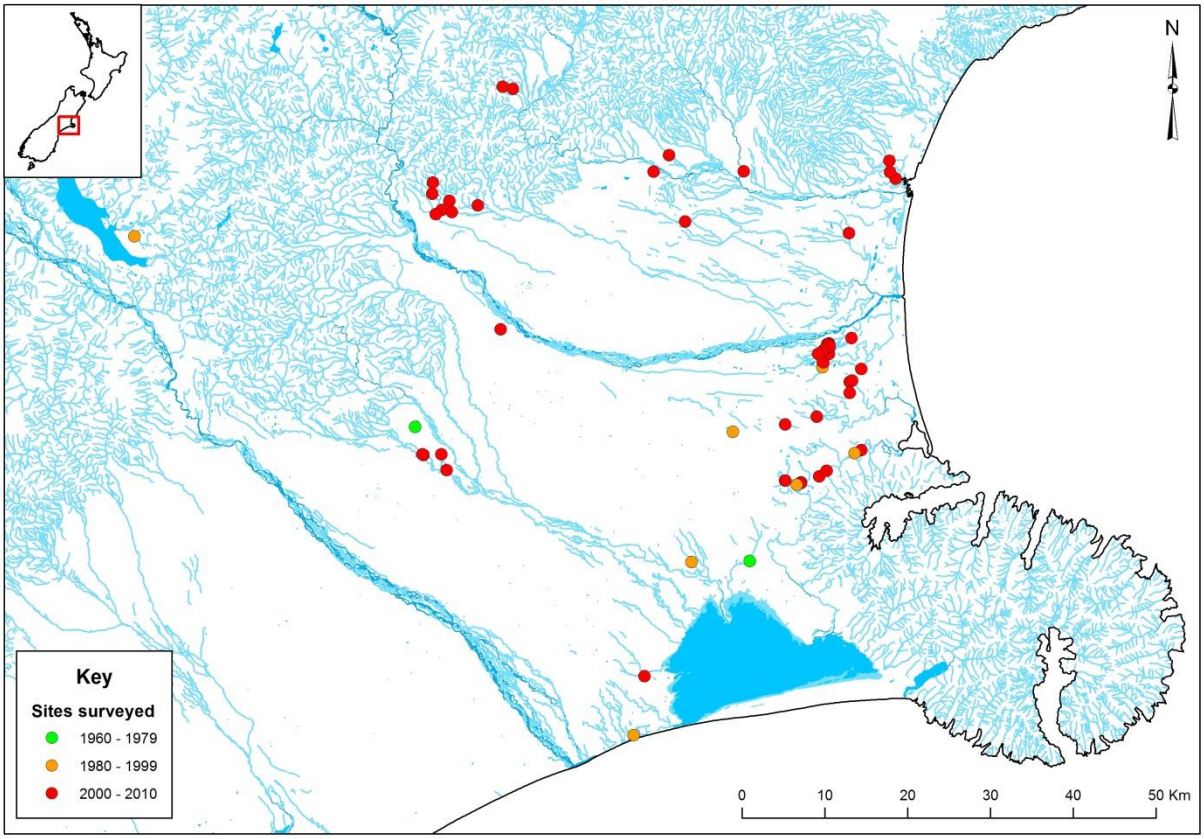

Figure 2.1 NZFFD sites assessed for kekewai. Some areas have not been assessed since the 1960's whereas some sites have been examined recently (data taken from NZFFD).

Māori consultation

I attended the 2013 "Living Lakes Symposium" at Lincoln University as well as the 2014 "Mahinga kai hui" held at the Christchurch Town hall and a "Tuna Wananga" at Ngāti

Moki marae that was run by Taumutu. From this I was able to make contact and meet some of the people that lived and worked in and around the systems I surveyed.

Potential kekewai sites were sourced from anecdotal evidence from prominent iwi representatives including assistance from kaitiaki (guardians/stewards) and local residents from Tūāhuriri and Taumutu. Information about historic and current kekewai sites was obtained from informal interviews as well as impromptu and casual conversations, with some of the people actively taking part in assisting with some of my sampling and physically guiding me to some of the locations.

As kekewai are a taonga (highly valued) species, and for some local peoples, still a valuable mahinga kai resource, information gathered from conversations with tāngata whenua (people of the land) was treated as strictly confidential. This detailed information is classed as intellectual property and therefore cannot be released without consent from the participating parties. Findings from investigating sites referred to by the informants was shared only with the people involved, however, if any of the sites had been previously recorded from other sources, then it was understood that information would be updated and reported.

There are many reasons why this information cannot be released and this includes factors such as traditional harvesting, whereby certain people have whakapapa (geneology) rights to a certain area and do not wish for it to be made public, or if a place is considered tapu (sacred) or has historical significance.

Site selection

I visited potential sites during the day to assess the habitat and determine if they would be suitable for kekewai. Severely degraded sites with obvious pollution were omitted. Potential kekewai habitats were then sampled by conducting spotlighting and hand-netting at night. These methods were used as they are common methods for sampling crayfish (Rabeni et al. 1997) and it is particularly suitable as kekewai are predominately nocturnal. Sites that were potentially hazardous or difficult were spotlighted from the banks, when kekewai were detected the site was noted as confirmed for presence. Some sites which had historical or anecdotal records of kekewai populations were visited 2 – 3 times if the first attempt was unsuccessful for detecting kekewai.

Waterways investigated for kekewai presence included streams, water races/pastoral drains, urban creeks, ponds, lagoons and lakes (Figure 2.2). All waterways were spotlighted

unless they were ruled out due to disturbance such as extreme macrophyte clearing. Unfortunately mechanical clearing happens in many lowland Canterbury waterways during spring and summer. In cases where the waterway had been completely cleared by mechanical means, the process may have removed a substantial amount of river bed along with the macrophytes. If after this process the habitat was degraded to the point that there was no sign of any remaining invertebrate or fish species present, the site was not examined. In addition to this, some waterways no longer existed or were dry due to development and land use modification and these were omitted from the survey.

Figure 2.2 Examples of water bodies that were surveyed. Starting from the top and going left to right are natural lake, pastoral water race, modified natural spring, natural spring feed water race, natural stream and spring fed suburban drain.

Sampling areas were categorised into land use type and water body type. There were three categories for Land use type; urban (U), suburban (S) and rural (R). Urban (U) was defined as being areas that had extensive residential or commercial development. Suburban (S) usually consisted of areas that were on the outskirts of the city and some of these areas were currently being or had recently been developed. These waterways tended to be flanked along one side by pasture or established bush. Rural (R), waterways were either situated in pastoral or established native/exotic or mixed bush. Water bodies were also categorised into three main types; natural (N), modified (W) and lentic (L). Natural (N) was defined as either naturally occurring water ways that were usually spring fed close to the sampling site, or those that maintained a natural meander and had well established riparian strips. Modified (W), mainly consisted of water races and drains. Lentic (L) were comprised of lakes, lagoons or ponds.

Comparison sites

Water chemistry samples were taken from five streams that had confirmed kekewai presence. In total, three water samples were taken from each confirmed site; the first was at the location where kekewai were detected and also at approximately 100m both upstream and downstream of the confirmed location. Five comparison streams were also sampled as above. These streams were around the same area as the confirmed sites. These streams did not have kekewai populations but had similar physical characteristics to the streams that did. This was so that comparative analysis could be conducted to determine which factors, if any may effect kekewai distribution. Water samples were collected from each of the sites as per instructions outlined by Hill Laboratories. They were collected in sample bottles supplied by Hill Laboratories and were not filtered. They were placed into an icebox and then transported to Hill Laboratories for a full suite of chemical analysis (Table 2.1).

Physical stream characteristics were also recorded at each of the comparison sites and include factors such as stream wetted width, water depth and sediment depth. These measurements were taken along three transect lines across each stream at approximately 20 m increments. Five to seven measurements across each transect line were recorded. Water depth was measured from the top of the sediment base to the surface of the water. Sediment depth was measured by pushing the ruler into the sediment until it reached hard substrate. Other observations include stream bed/substrate composition which were divided into three main categories silt/sand (<0.6 – 2 mm), gravels (>2 – 64 mm) and cobbles (>64 – 256 mm) and

macrophyte growth. These parameters were visually assessed at the transects and are approximations. Stream temperature was measured using YSI 550A probe.

2.3 Results

In total, 78 sites were surveyed and 57 of these were registered in the NZFFD. Of these 57 sites, 20 had previously confirmed kekewai presence between 1985 – 2005 (Figure 2.1). I did not detect any kekewai in any new sites that did not previously show kekewai presence. However, kekewai were only found in 12 (15%) of the 78 sites surveyed (Figure 2.3).

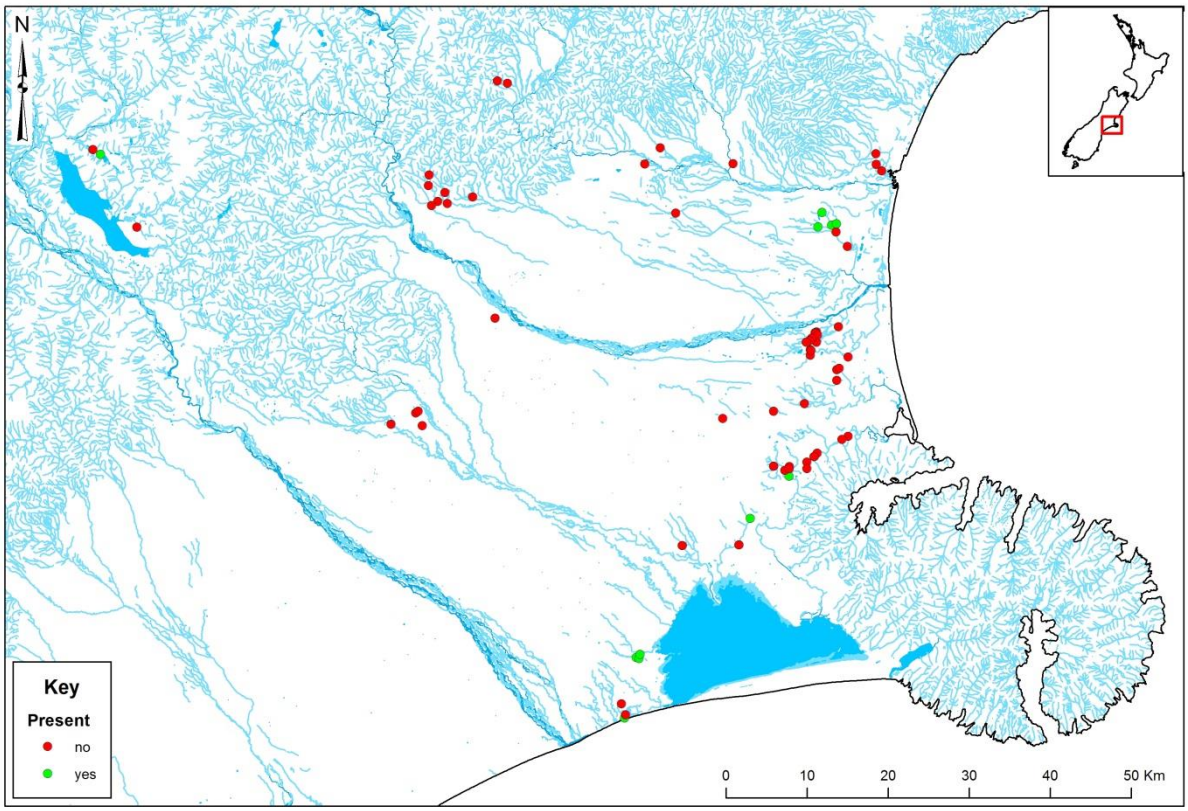

Figure 2.3 Sites examined over the summers of 2013/14 and 2014/15. In total, kekewai were present in 12 of the 78 sites surveyed. NB. In addition to the sites shown, there were 5 sites that are not recorded on this map. These 5 sites are culturally significant and are classed as intellectual property.

Of these 12 sites where kekewai were present, eight were in rural areas and four were in suburban areas. There were no kekewai detected in any of the urban water bodies. The rural sites included five rural (R) natural (N) waterways, one was a rural (R) water race (W) and two were rural (R) lentic water bodies (L). For the suburban areas, three were suburban

(S) natural (N) waterways and one was a suburban (S) drain (W). The largest kekewai (> 50 mm) were observed and captured in two of the rural sites. One of these was a natural spring fed stream and the other was a natural lagoon. (Figure 2.4). Although both of these sites were within the same geographical area, they were not tributaries of the same water body. Another rural stream had the quickest detection and capture than all other sites with seven kekewai caught in under 10 minutes. In addition to the sites that have been recorded, I investigated five sites that were culturally significant to iwi and therefore are not included on the map. I detected kekewai in two of these sites but was unable to detect them in the other three.

Figure 2.4 Kekewai captured in the South of Christchurch were the largest specimens caught from all sites

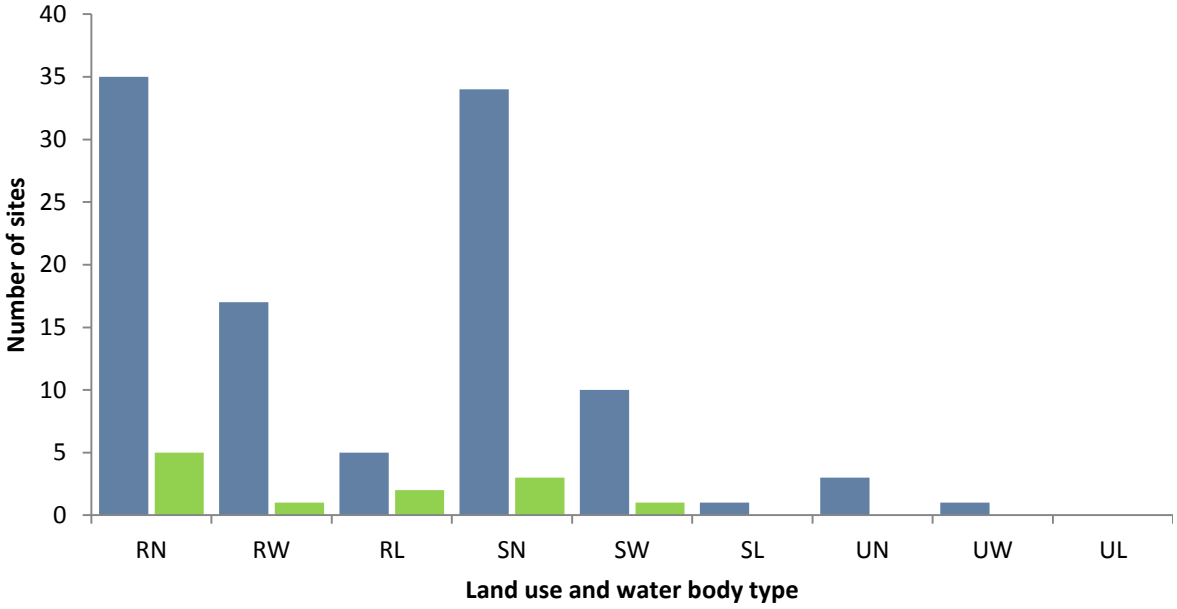

Figure 2.5 Total number of sites surveyed with land use rural (R), suburban (S), urban (U) and water body type, natural (N) water-race/drain (W) or lake/lagoon/pond (L) (blue). Numbers of kekewai sites for each land and water type are also shown (green)

Sites where kekewai were present

Some of the sites used in the comparison study are culturally sensitive to iwi and therefore cannot be identified. Because of this, all sites are coded so as not reveal their locations. Site assessments were not measured quantifiably but are more qualitative descriptions. Sites A and B were situated north of Christchurch, whereas sites C and D were south of Christchurch and site E was southwest of Christchurch. Site A was a natural spring fed first order stream. It was a cobbled bottom stream but was also inundated with heavy silt sedimentation for much of the stream bed area. A hawthorn hedge ran for approximately 50 m along the north side of the stream. Very few macrophytes grew where the hedge was, however macrophyte growth was prolific along the rest of the waterway. Only one specimen was hand netted at this site during the surveys, however, many more were observed.

Site B, was a pastoral stream that was flanked on both sides by vegetation. This stream had high banks that were > 4 m in some parts. It was a cobbled bottom stream with some silt sedimentation inundation covering approximately 20% of the stream bed, however the sediment was not too deep and the cobbles could be felt underneath when walking along the bed. Approximately one third of the plants were large established trees that provided shading over the stream for most of the day. Only one large specimen was captured at this site.

Site C was situated south of Christchurch, although this was a pastoral stream there had been stream rehabilitation efforts in place for some time which is evident in riparian plantings that are becoming established. This stream had a mixed substrate composition which included silt, fine sediment gravels and larger cobbles lining the stream bed. There were also potholes along the bed which were obscured by heavy macrophyte growth. The stream was very deep in some parts which meant that sampling was restricted. Kekewai were observed in macrophytes but no specimens were caught.

Site D, also south of Christchurch emptied into a lagoon, although flanked by pasture on both sides with no apparent large riparian vegetation to offer shade, it was relatively cool due to the fact that it was a spring fed system. This site was also cobbled bottomed and had a moderate amount of macrophyte vegetation. Site D, had the largest specimens out of all of the sites surveyed (Figure 2.3).

Site E was situated south west of Christchurch, it was a suburban area that fringed rural farmlands. Approximately 200 m from where I sampled was where the waterway began, it was a spring fed system that started in a pastoral paddock but then meandered through a built up well established suburban setting and for most of its length, ran parallel to a main road. The stream bed was dominated by cobble with silt inundation in some parts.

Sites where kekewai were absent

Site A* was situated approximately 3ks from site A. Similar to site A, it was in an area that had been developed and had been replanted. The stream bed was mostly silt sediment over cobbles. There was a lot more human activity around this area and the road near to the stream was quite busy.

Site B* was also pastoral however the stream was approximately four times wider than that of site B. There were a few established trees along one side of the stream and the

other side was pasture. There was very little silt sedimentation at this site and the stream bed was mostly a mixture of gravels and cobbles. There were very few macrophytes present. However predatory fishes, mainly trout were present in this stream.

Site C* was also pastoral, however there had been very little efforts to rehabilitate the stream. Riparian cover is minimal and consisted of pasture with few trees and shrubs. Heavy silt sedimentation covered much of the stream bed and bank slumping was also observed. Macrophyte growth was patchy.

Site D* was not from the same area as site D, mainly because it was difficult to find another system without kekewai that emptied into a lagoon. However, the comparison site was a stream that emptied into a modified widening of a waterway that acted as a lagoon. Stream bed was cobbled bottom with very little silt inundation. There were some macrophytes within the stream and also some large trees along the bank.

Site E* was in a similar setting to Site E, flanked by suburban housing along most of the stream length. The stream bed was primarily cobbles with some smaller gravel particles. Of all the sites surveyed, sites E and E* would be considered to be the most urbanised of all the stream systems.

There was significantly more sediment deposition in the waterways without kekewai than those with confirmed kekewai presence ($F_{1,8}$ = 6.3, P = 0.03). Temperature was also significantly different between sites with and those without kekewai ($F_{1,8}$ = 9.21, P = 0.02). Although there did appear to be differences for potassium concentrations between sites with and without kekewai, they were not significant ($F_{1,8}$ = 4.7, P = 0.06). All other factors were similar (Table 2.1).

Table 2.1 Stream properties and water chemistry from a total of 10 locations with (5) and without (5) kekewai. * represents the range of mean values. Analysis conducted by Hill Laboratories are shown as *

Variable (unit)	Kekewai present (5)		Kekewai absent (5)		
	Range (min-max)	Mean (SE)	Range (min-max)	Mean (SE)	P value
Wetted width (m)	1.8 – 5.5	3.9 (0.5)	2.5 – 8.0	5.6 (0.9)	0.16
Water depth (cm)	26.6 – 53.3*	34.2 (5.1)	19.8– 43.6*	29.9 (5.1)	0.56
Sediment depth (cm)	14.7 – 28.4*	17.7 (5.9)	19.0 – 45.6*	31.2 (10.5)	0.03
Temperature (°C)	13.4 – 15.1	14.0 (0.3)	14.8 – 17.0	15.9 (0.4)	0.02
pH*	7.5 – 7.8	–	7.5 – 7.9	–	–
Total Alkalinity (g/m^3as $CaCo_3$)*	43 – 51	46.6 (2.4)	42 –59	50.6 (4.5)	0.45
Bicarbonate (g/m^3 at 25°C) *	48 – 62	57.0 (2.7)	51–77	61.2 (5.3)	0.50
Total Hardness (g/m^3 as $CaCO_3$)*	42 – 86	61.4 (10.3)	40 – 87	60.0 (10.8)	0.92
Dissolved Calcium (g/m^3)*	11.9 – 25	18.5 (2.8)	12.3 – 27	18.1 (3.2)	0.93
Dissolved Magnesium (g/m^3)*	2.2–6.0	3.8 (0.8)	2.2 – 5.6	3.5 (0.7)	0.84
Dissolved Potassium (g/m^3)*	0.9 – 1.2	1.1 (0.06)	1.1 – 1.8	1.4 (0.1)	0.06
Dissolved Sodium (g/m^3)*	6.0 – 14.9	9.8 (2.0)	6.4–21.0	11.4 (2.9)	0.66
Chloride (g/m^3)*	3.8 – 18.1	9.9 (3.3)	3.8 – 21.0	10.2 (3.6)	0.96
Total Ammoniacal-N (g/m^3)*	<0.010–0.01	–	<0.010 – 0.02	–	–
Nitrite-N (g/m^3)*	<0.002 - 0.005	–	<0.002 – 0.013	–	–
Nitrate-N (g/m^3)*	0.6 – 7.6	3.7 (1.5)	0.6 – 5.8	2.5 (1.1)	0.53
Nitrate-N + Nitrite-N (g/m^3)*	0.6 – 7.6	3.7 (1.5)	0.6 – 5.9	2.5 (1.1)	0.55
Dissolved Reactive Phosphorus (g/m^3)*	<0.004 – 0.008	–	0.002 – 0.046	–	–
Sulphate (g/m^3)*	5.4 – 10.6	8.0 (1.0)	6.5 – 16.1	9.8 (2.0)	0.46

2.4 Discussion

Worldwide, there has been a marked decline in native crayfish populations with many crayfish species being considered threatened or at risk of extinction (Taylor et al. 1996, Ricciardi and Rasmussen 1999, Holdich 2002). The main factors associated with the decline

of crayfish species are habitat modification, pollution, predatory fishes and competition from invasive species (Taylor et al. 1996, Holdich 2002). Kekewai were present in the current study in less than 16% of all the sites surveyed and at times were not detected in places where they had been previously recorded in the NZFFD. As most of the water bodies I investigated had some degree of modification, this could have affected recruitment and population densities (Parkyn et al. 2002) and could explain why kekewai were difficult to detect. However, because they appear difficult to detect could also suggest that populations are declining. In total, I was able to confirm that kekewai were present in 12 waterways. *P. zealandicus* is currently listed in the 2013 New Zealand threat classification series as being potentially in decline between 10 to 70% (Grainger et al. 2014). Results from the current study of *P. zealandicus* in central Canterbury suggest that a 10% reduction is conservative.

Freshwater crayfish distributions are often patchy (Sibley et al. 2002). In the present study some positive kekewai sites were clustered and others were isolated. The two isolated sites were more than 100 km apart and were not connected to the same tributary therefore there is no possibility that the same populations could have been surveyed. The clustered sites North of Christchurch were tributaries of the same river and there was potential for recruitment and immigration between the waterways. Hobbs (2000), cited in Maguire and Gottstein-Matočec (2004) states that hydrological structure and climatic conditions play an important role in supporting both active and passive dispersion of crustaceans. Therefore, finding clustered populations in tributaries of the same river system is not unexpected. As these sites were still some distance apart (> 5 km), it is highly unlikely that I could have sampled the same animals at the different locations even if sampling periods were more than a year apart.

For one of the sites north of Christchurch, there was in place a physical barrier that could have impeded kekewai immigration and emigration. This barrier was in the form of a trout gate that was erected to obstruct trout from entering the kekewai sanctuary. This was not totally successful as we did observe trout in the main kekewai area. However, recently there have been some repairs and modifications which could make this barrier more successful.

Three kekewai sites south of Christchurch were tributaries of the same main water body and there was potential for recruitment between these populations. However, crayfish are relatively slow dispersers, it took more than 16 years for the invasive signal crayfish (*Pacifastacus leniusculus*) to disperse over a distance of 10.4 km in North Yorkshire U.K

(Bubb et al. 2004). Bearing in mind that this particular crayfish has the ability to migrate over land (Scott 2000) and is considered to be a successful invader, this is regarded as a fast dispersal rate. Monitoring of the native European crayfish (*Austropotamobius pallipes*) in Wiltshire, found that after one year, crayfish had dispersed approximately 150 m (Spink and Frayling 2010). Water velocity may not be a contributing factor in crayfish dispersal. This was highlighted by a study conducted by Bubb et al (2004) which found that distances that crayfish travelled was a result of active movements rather than passive movements during high discharge periods.

The remaining two kekewai sites south of Christchurch were not connected to other confirmed sites but were tributaries of separate waterways. One of these sites is a headwater spring that is a tributary of a larger waterway which has historically been inhabited by kekewai. As I did not sample past the confluence, I cannot confirm kekewai absence or presence in the greater system. The other stream site I sampled was at the mouth of a lagoon and it was at this site that the largest kekewai were caught. As this waterway was quite deep and was connected to a lagoon, it could account for the larger sizes of the specimens, as according to Devcich (1979) who studied *P. planifrons* in Lake Rotoiti, larger sized individuals are often found in lakes. Whitmore and Huryn (1999) contradict this, with their study finding that large *P. zealandicus* are also present in headwaters of Powder Creek, Otago. It is unclear what factors are attributed to the larger sizes in this stream, however, the age and long life span of the species could account for some of this. Other factors that could account for larger individuals are water depth and predation pressure. The lagoon in the present study is relatively predator free, with no eel or trout populations.

Previous records of kekewai distribution in the NZFFD database listed 20 sites that with kekewai populations prior to 2006. I confirmed kekewai were present in only 15% (3). This does not necessarily mean that there are no kekewai in the other water ways, however, difficulty in detecting them could be an indication of decreasing population numbers. For example, two of the Styx river tributaries had kekewai in 1990 (NZFFD), but, none we detected in these sites in this survey. These areas were sampled more than once as there had been recent reports of freshwater crayfish in the stream system (Thestyx.org.nz 2016).

Of the three sites with kekewai populations, two had been surveyed recently in 2003 and 2005, however the third site was last surveyed in 1997. There were also sites that had not been assessed since the 1980's. The large temporal gap between assessments highlights the

need for more intensive monitoring of our freshwater ecosystems. To ensure that our native species can persist, we need to be more vigilant about populations and distributions and more aware of habitat changes that could potentially become ecological threats.

Streams even within a particular area are likely to differ in their physical, chemical and biological attributes (Roper et al. 2002). In the present study using attributes such as stream width, vegetation type and water depth, it was difficult to sample sites with similar characteristics. None of the measured attributes explained the presence or absence of kelewai. The only measured factors to be significantly different between streams with kekewai and those without were sediment depth and temperature. Although temperatures were different, they are subject to fluctuations for both time of day and season, therefore this difference could be attributed to time of sampling. Deep sediment measurements are often indicative of fine silt, whereas shallow sediment depth correlates to larger more stable particles (J.Harding, pers.comms 2009). Kekewai are considered to be active burrowers and can be found in areas with some silt sedimentation (Whitmore et al. 2000). However, the threshold for sediment tolerance is not clear and other variables such as in-stream vegetation and riparian growth may contribute to kekewai presence (Whitmore et al. 2000). Heavy sedimentation can have detrimental effects on aquatic fauna and in particular macroinvertebrate colonisation (Richards and Bacon 1994). This is largely due to alterations of the physical habitat caused by clogging of interstitial spaces, which reduces potential habitat for benthic invertebrates (Clapcott et al. 2011).

Like many macroinvertebrates, crayfish use interstitial spaces for foraging and refugia (Taylor and Redmer 1996), and large kekewai (>8 mm OCL) show a preference for cobbles over fine sediments and boulders (Jowett et al. 2008). This could be because fine silt sediments are unsuitable habitat for many species of macroinvertebrate prey (Richards and Bacon 1994, Jowett et al. 2008). Boulders may offer no protection to crayfish from predatory fishes (Jowett et al. 2008). Within cobble habitats sediment inundation is of major concern, especially when interstitial spaces are no longer present. These are also used by other macroinvertebrates, inundation therefore reduces potential food sources for kekewai.

Although spotlight and hand netting is a common method for sampling crayfish (Rabeni et al. 1997), in retrospect it may not be the most reliable method for detecting kekewai. This is mainly because it is restricted to situations of high underwater visibility. Although macrophyte cover was extensively searched, they did still provide substantial cover

which made it difficult to spot crayfish. I would recommend the use of multiple sampling methods to effectively monitor current kekewai populations. However, the type of sampling methods that could yield the most accurate results for both distribution and population sampling were not yet determined, but have been investigated in Chapter 3.

Habitat degradation is one of the leading causes of world-wide species decline (Taylor et al. 2007) and interactive effects between land-use change and biotic exchange are widely considered to be important drivers of biodiversity loss (Didham et al. 2007). These losses are often the result of environmental stressors. There are many factors that contribute to habitat degradation including pollution, invasive species, increased land productivity and modification or alteration of habitat (Wilcove et al. 1998). For kekewai, in the present study, habitat degradation and in particular sediment inundation are perhaps the most concerning issues that are threatening the species' persistence in central Canterbury. These factors, along with other stressors such as invasive predatory fishes mean that kekewai are highly threatened.

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Assessment of trapping methods for freshwater crayfish

3.1 Introduction

Worldwide, freshwater crayfish are captured for a variety of reasons including traditional harvesting and cultural food gathering (Jussila and Mannonen 2004, Jones and Coulson 2006, Crandall and Buhay 2008) as well as recreational and commercial fishing (Balık et al. 2003, Harlioğlu and Harlioğlu 2004, Jones and Coulson 2006). Trapping is also practiced for pest removal, particularly in Europe where invasive crayfish are a significant problem (Hein et al. 2007, Freeman et al. 2010, Gherardi et al. 2011). However crayfish are also used for biodiversity assessment (Dorn et al. 2005, Price and Welch 2009). There are many different types of capture methods including baited and un-baited trapping, netting, hand capture and electric fishing (Rabeni et al. 1997, Acosta and Perry 2000, Alonso 2001, Balık et al. 2003, Dorn et al. 2005).

Traditional subsistence and commercial harvesting

Subsistence harvesting of the endemic crayfish (Parastacidae; *Astacoides*) in Madagascar, is carried out using customary techniques involving hand capture by overturning rocks and fishing with baited sticks under large boulders or in bank cavities (Jones and Coulson 2006). Some of these traditional methods are also used to secure crayfish for local trade (Jones and Coulson 2006, Crandall and Buhay 2008). In Finland, traditional and recreational fishing methods include trapping, hand capture, baited rod and line fishing and dip nets (Jussila and Mannonen 2004).

The most common method of capture used by commercial fisheries, is trapping using a variety of baited trap types (Jussila and Mannonen 2004). Traditionally, commercial crayfish trapping in Turkey consisted of cylindrical net traps with funnel entrances at each end (Harlioğlu and Harlioğlu 2004), although these are still sometimes employed, a more modern approach to crayfish harvesting has been the implementation of fyke nets (Balık et al. 2003).

In New Zealand, Māori employed a variety of techniques to capture kekewai such as capturing by hand, fishing with bait tied to string and in-situ net trapping, and many of these techniques are still in use today. However, the most common traditional traps used by Māori for harvesting kekewai were called tau-kōura and can be deployed in both lentic and lotic freshwater systems. Tau-kōura are comprised of bundles of bracken fern and are placed on the bed. Kekewai then colonise the ferns over several days.

Pest removal and control of invasive crayfish species

The removal of invasive crayfish often depends on manual fishing techniques such as netting and electrofishing or mechanical methods such various types of set trapping (Freeman et al. 2010). For example, gee-minnow traps have been used to reduce invasive rusty crayfish (*Orconectes rusticus*) populations in Sparkling Lake in northern Wisconsin, U.S.A (Hein et al. 2007). An intensive trapping regime was combined with regulated restriction of fishing predatory fishes which greatly reduced invasive crayfish numbers over a five year period (Hein et al. 2007). Although these techniques are effective in removing crayfish, they are time intensive and there is uncertainty that eradication of established populations could be achieved (Freeman et al. 2010, Gherardi et al. 2011). A review of different methods employed to remove invasive crayfish species found that when trapping ceased, populations returned to previous levels within a couple of breeding seasons (Gherardi et al. 2011). This could be attributed to the many limitations that are often associated with trapping. For example, there is much literature suggesting different types of traps are more effective for particular sexes and they may also be size selective (Westman et al. 1999, Moorhouse and Macdonald 2011).

Sampling crayfish populations

Crayfish collection and sampling can be grouped into two main categories; active sampling or passive sampling. Active sampling methods include techniques such as electric fishing, seine netting, dip net and hand capture and throw trapping. Throw trapping uses a trap consisting of a deep frame covered by mesh on the sides, whilst the top and bottom are open. The trap is thrown into the water to trap crayfish which are then retrieved. Passive sampling includes techniques such as fyke nets, gee-minnows, tau-kōura or other in-situ set trapping. Most of these sampling methods have been used with varying degrees of success to estimate crayfish populations. With the exception of electric fishing however, many techniques show strong biases (Price and Welch 2009). For example, gee-minnows appear to

be strongly biased towards males and larger individuals (Somers and Stechey 1986, Dorn et al. 2005, Price and Welch 2009), whereas seine netting tends to capture small juveniles over adults (Price and Welch 2009). Bias towards capturing large males has been considered to be because males have more active foraging behaviour compared to that of females and juveniles (Armitage 2000).

To determine robust abundance and distribution information, non-biased sampling methods are required; however, estimations of abundances of crayfish are often fraught with confounding variables. Effective and objective approaches are required for sampling population dynamics and investigating factors that might affect distribution and abundance. Often the type of trapping method selected may be reliant on other variables that need to be considered. These can include factors such as unwanted trapping of non-target species and in particular predatory species which might deter target species.

When studying crayfish populations it is often necessary to investigate associated species, vegetation, potential predators and food availability. For these reasons, it can be prudent to use a combination of sampling methods. However, this may not be practical because of costs, time, man power or available resources. Therefore, it is necessary to define clear questions behind trapping and employ selected trapping methods and techniques to address these.

Trapping equipment and techniques

Traditional capture and harvest of kekewai using tau-kōura

The tau-kōura is a traditional kekewai harvesting method employed by the indigenous Māori peoples of New Zealand. Traditionally it is comprised of stems of aruhe bracken fern (*Pteridium esculentum)* which are then bundled together to form whakaweku (Kusabs 2015). These bundles are then placed into a lake or stream, often for more than six weeks, which allows the bracken to start to decompose. The main aim is for kekewai to colonise the tau-kōura and leaving the trap to remain in-situ for several weeks will allow for greater colonisation. Some iwi (tribes) use baited tau-kōura to catch kekewai overnight. These can be baited with any firm meat such as steak, to attract rapid colonisation. This method is successfully implemented for capturing *P. planifrons* in Northland (Pohe, pers. coms).

Tau-kōura have been successfully used to harvest kekewai for many generations. Despite the long tradition of using tau-kōura, relatively little research has been done on the

efficiency of this technique. Colonisation of tau-kōura could be attributed to several factors including provision of habitat refugia from predators, the structural complexity which reduces cannibalism or availability of bracken as an additional food source. To investigate whether it is the refugia aspect that attracts kekewai, I conducted experiments using artificial tau-kōura and compared them with natural fern tau-kōura.

Fyke nets

Fyke nets, also often referred to as hoop nets, are cylindrical shaped nets with the first hoop being horseshoe shaped (Atar et al. 2002). They operate by using a leader net that guides the animal into the funnel entrance. These traps enable the animal to enter whilst impeding escape by use of a no-return device between the fourth and sixth hoops in larger fyke nets (Atar et al. 2002), or between the second and third hoops in smaller fykes. This trap type is very successful for crayfish capture and is often used by commercial fishermen in Turkey (Balık et al. 2003). Size of individuals and number of animals caught, using fyke nets have been shown to be significantly higher for crustacean species than some other trap types such as box traps which are functionally similar to minnow traps (Atar et al. 2002, Balık et al. 2003).

Gee-minnow traps

Gee-minnow traps are cylindrical galvanised mesh traps with funnel entrances at each end and can be deployed with or without bait. The funnel entrances guide animals into the trap, which make it easy for animals to enter, whilst also impeding escape. It is similar to a fyke net, but is often smaller and does not have a leader net to direct animals into the funnel. Gee-minnow traps are often used in sampling both freshwater fishes and crayfish and have been successfully used overseas to capture and remove pest species (Hayes 1989, He and Lodge 1990, Jackson and Harvey 1997, Chucholl 2011, Moorhouse and Macdonald 2011).

Hand net capture

Hand netting is a common method for capturing crayfish species for harvesting (Rabeni et al. 1997, Jussila and Mannonen 2004). Although freshwater crayfish can be active during the day they are mostly nocturnal, therefore hand net capture is more successful when performed at night. Spotlighting at night not only enhances overall stream visibility but increases the chances of crayfish detection as their eyes reflect the light. This method often shows bias towards large males which is attributed to the fact that males are considered to be

more active than females and will venture further to forage or to seek a mate (Armitage 2000).

Electric fishing

Electric fishing, also known as electrofishing (Dorn et al. 2005) is often performed by using a backpack with a wand that emits a pulsed current that temporarily stuns animals. Portable backpack electric fishing units are often employed in streams and rivers. Operators can carry out 1 – 3 passes within a set area. When this method is performed correctly, stunned animals are quick to recover and can usually be handled and sampled within minutes of capture. Correct use of this method can also ensure that animals do not tend to suffer any long-term or permanent after effects and can be released safely back into the environment (Schill and Elle 2000, Beaumont et al. 2002).

Research aims and hypotheses

1. Comparison of the effectiveness of different capture methods

The aims of this study were to compare the effectiveness of the three passive trapping methods; gee-minnow traps, fyke nets and tau-kōura and two active fishing methods; electric fishing, and spotlighting. From previous studies, I predicted that of the passive methods gee-minnow traps would be biased towards large males, fyke nets would favour larger individuals and that tau-kōura would not bias for size or sex. For active sampling methods, I predicted that electric fishing would not bias towards size or sex and that spotlighting would favour males. The null hypotheses were that there would be no size or sex biases for either active or passive capture techniques.

2. Comparing recruitment and colonisation of artificial and natural tau-kōura

Little is known about why kekewai use tau-kōura and how long it takes. Kekewai may colonise tau-kōura because they offer refugia or are a potential food source. I compared colonisation of natural and artificial tau-kōura. If they use this primarily as refugia, there will be no difference for recruitment of kekewai between natural and artificial tau-kōura.

3.2 Methods

Study sites

Study reaches for trapping trials were selected from waterways with confirmed kekewai presence during my initial survey (Chapter 2). Of the three streams selected, two were situated north of Christchurch (Figure 3.1), Northbrook (43º 18´ 31. 64 S, 172º 36´ 29. 98 E) and Marsh Road (43º 19´ 23. 66 S, 172º 37´ 24. 41 E) and one was south of Christchurch, Liffey Springs (43º 38´ 50. 11 S, 172º 29´ 47. 98 E). Both Northbrook and Liffey Springs were first order streams, whereas Marsh Road is a second order stream (Figure 3.2). Physical characteristics of reaches are shown in Table 3.1. In each waterway, a ~100 m reach was selected for sampling. At each site, six sampling station markers were placed at approximately 20 m intervals from the most downstream position. With the exception of fyke nets, sampling was conducted at each of the marked sampling stations.

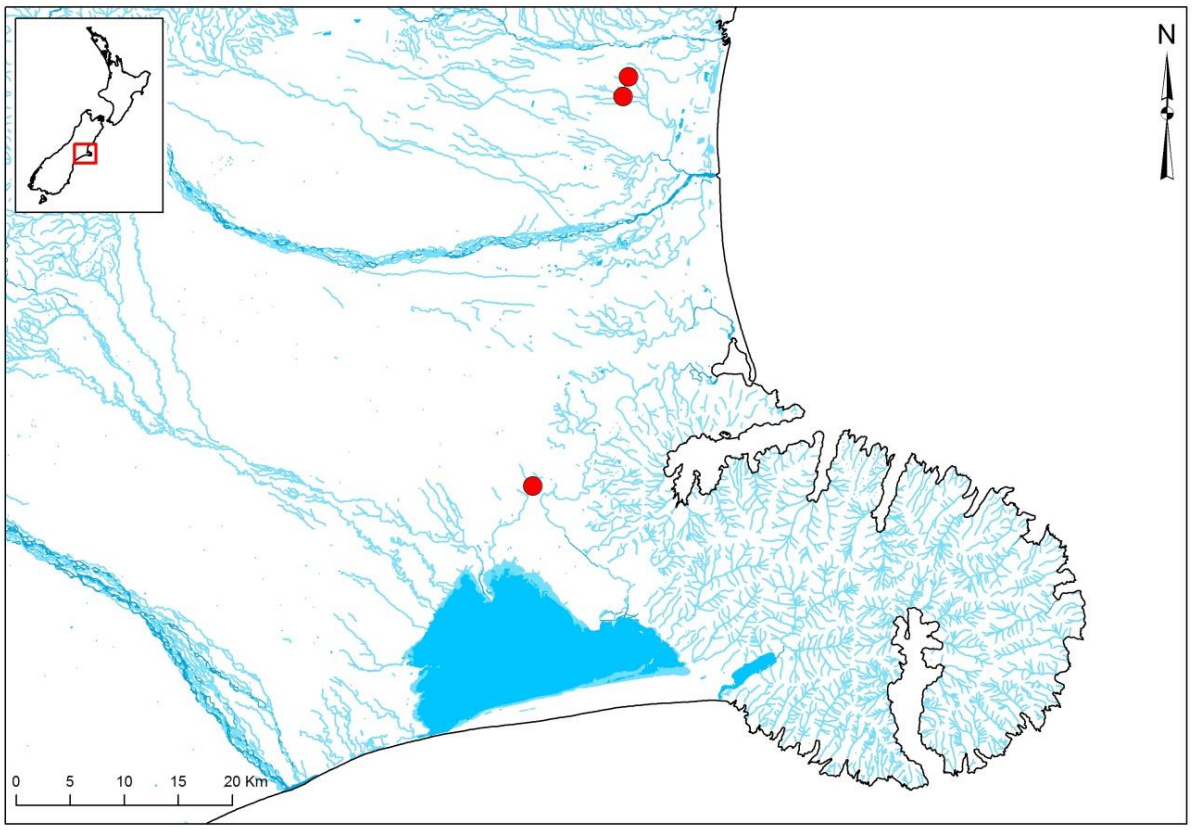

Figure 3.1 Locations of trapping sites used in the present study. Northbrook and Marsh Road were in the same catchment near Rangiora.

Figure 3.2 Upper and lower stretches of the three stream reaches used in this study. From top to bottom Northbrook, Marsh Road (Rangiora) and Liffey Springs (Lincoln)

Active sampling methods

Spotlight and hand net capture

Spotlight and hand net capture was conducted at night. In total 6 m were sampled at each of the sampling stations. This was to ensure that areas searched covered a similar area to that of other methods used in the present study. Spotlights used were Light Force Predator with 30 w halogen bulbs, powered by 12 v batteries which were carried in backpacks. Hand nets used were round, 28 cm diameter, 2 x 2.5 mm mesh size, 25 cm depth with a 150 cm long handle.

At all reaches, sampling began downstream. As many of the sites were soft sediment bottoms, spotlight and hand net capture began 3 m downstream from each sampling station

and then the sweep was up to 3 m upstream of the sampling station. This was to lessen the effect of disturbed sediment clouding the water and inhibiting vision and kekewai detectability. Captured kekewai were placed in buckets filled with stream water until site sampling was completed. Non-target species were noted as present and identified to nearest genus, but were not caught and measured. Once the site had been sampled, kekewai were measured and sexed and life stage was recorded before they were released.

Electric fishing

Electric fishing was performed using a portable backpack Kainga EFM 300 (Figure 3.3), all operators held a certificate of completion for the Electric Fishing Machine Operators Course conducted by the National Institute of Water and Atmospheric Research (NIWA). The use of electric fishing for sampling was with Animal Ethics approval (2013/38R).

Electric fishing using the one pass method was performed in a 6 m stretch encompassing 3 m either side of markers. Due to high levels of silt sedimentation and dense macrophyte cover, fishing began at the furthermost downstream sampling station and was conducted by wading upstream. Push nets and dip nets were used to capture stunned animals that were floating in the water current, these were then transferred into buckets. Kekewai were contained separately from non-target species with juveniles and adults also contained separately. For kekewai, orbit carapace length (OCL), sex and life stage were recorded. Non target species were identified and measured. Target and non-target specimens were recorded as per previous methods.

Figure 3.3 Electric fishing in an urban stream

Passive sampling methods

Gee-minnow trapping

Commercially available, cylindrical galvanised wire gee-minnow traps, measuring in length 42 cm and 23 cm at the widest diameter and approximately 6 mm square mesh. These were fastened with stainless steel trap clips, which were then tethered to poles. Whilst trap opening diameters can be as small as 20 mm, I selected traps with larger opening diameters between 40 – 50 mm to allow for capture of larger specimens (Figure 3.4).

At each sampling station, one gee-minnow trap was placed in the bottom of the stream close to the bank with the openings parallel to flow direction. Gee-minnow traps were pressed lightly into soft sediment approximately 10 – 20 mm to help secure them so that they would not be disturbed by stream flow. The traps were set for a 24 h period at each of the sampling sites. They were then uplifted and all specimens both target and non-target species were placed in buckets according to size. All kekewai were measured, sexed and life stage and abnormalities were recorded, non-target specimens were identified and measured. Smaller kekewai were released first, followed by larger kekewai. Non-target species were released last. Traps were then baited with a spoonful of marmite, inserted into plastic film canisters that had piercings to allow for water to flow through and then reset for another 24 h period. After 24 h they were uplifted and kekewai and non-target specimens were recorded.

Figure 3.4 Galvanised steel gee-minnow traps that were used both baited and un-baited during passive trapping trials.

Fyke nets

The fyke net traps consisted of four reinforced metal hoops, a 50 cm diameter horseshoe shaped frame opening that narrowed to a 20cm funnel with a non-return funnel device between the second and fourth hoops. Each fyke net trap had a 2.5 m leader net (Figure 3.5). A fyke net was placed at 3 sampling stations at each site. These were baited in a similar fashion to the other baited trapping gears with marmite placed in film canisters. They were deployed during the day, left out overnight and uplifted the following morning. Both target and non-target specimens were recorded and then released as per the previous methods for sampling. The number of animals caught using a specific method or technique is often referred to as catch per unit effort (CPUE). This trap method was selected because it is highly successful for capturing freshwater crayfish and has been shown to have a greater CPUE than other trapping methods.

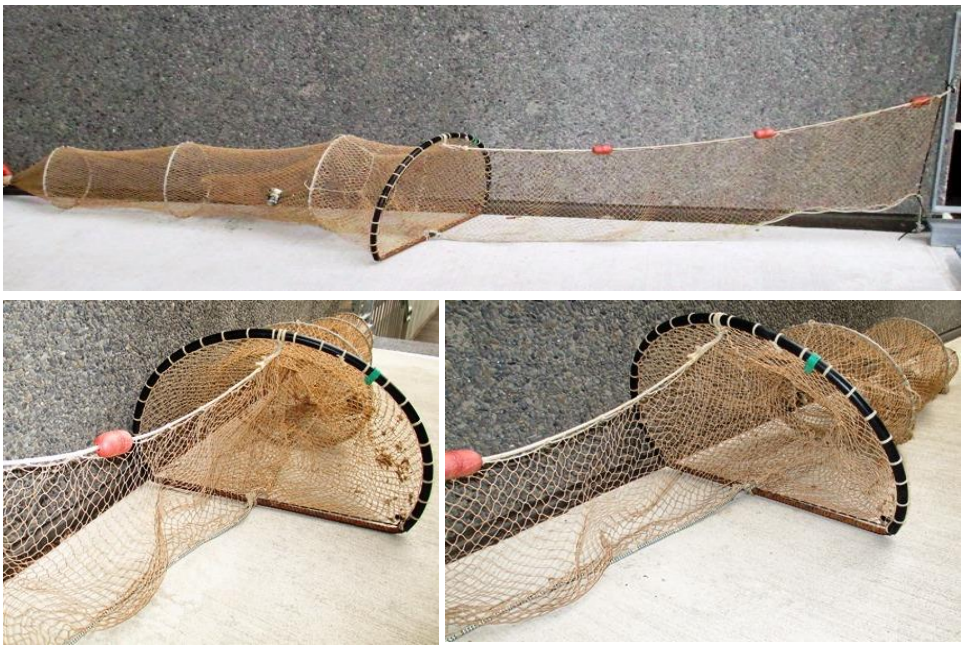

Figure 3.5 Fyke nets used in passive trapping trials. The length of the fyke net trapping devices were more than double that of other passive trap types used in the study

Tau-kōura

In total, six tau-kōura containing 12 fronds per whakaweku were used at each site (Figure 3.6). Bracken ferns were harvested from Te Kōhaka o Tūhaitara, they were then brought back to the laboratory, cut to approximately 1 m lengths and constructed into tau-kōura. The whakaweku were bound around the bottom stems with zip ties and the same metal

clips and twine that were used to tether the minnow traps to the stream banks were also used to tether the tau-kōura. The tau-kōura were placed in the streams close to the bank with the widest end facing downstream. Most of the tau-kōura were able to be secured to the bottom of the stream bed with a metal U clip through the zip ties at the bottom end, however, some needed to be weighted down with rocks to prevent them from floating to the surface. All tau-kōura were deployed over a single night. All specimens captured were recorded and then the tau-kōura was redeployed. Tau-kōura were used twice, both baited and un-baited. Baited canisters were secured to the tau-kōura with cable ties. Tau-kōura deployed at Marsh Road and Liffey Springs were wet weighed prior to experiment commencement. At the conclusion of the experiment, all tau-kōura were dried in a glass house for approximately three weeks and then reweighed.

Figure 3.6 Tau-kōura used in trapping trials. Left to right: showing before deployment, submerged tau-kōura and uplifted tau-kōura.

Experiment design

Bait selected was marmite which was placed into film canisters that had been punctured to allow water to flow through. Preliminary trials using lambs kidney, gravy beef and cat food failed to attract kekewai, therefore I decided to use marmite as it is commonly used in New Zealand as an attractant in traps to capture freshwater species.

The order of sampling method was randomly selected, however, due to the intrusive nature of the electric fishing method this was always performed last. The electric fishing method was the only technique to be performed only during the day, all other treatments were

performed either at night or over a 24 h period. Set trap methods such as gee-minnow, fyke net and tau-kōura remained in-situ for approximately 24 h. Baited and non-baited traps were performed consecutively, so if the gee-minnow trap type was selected, I did both conditions, non-baited for the first 24 h and then baited for the next 24 h period. Each capture method was trialled once per site per stream. Kekewai caught were measured and sexed and then released, non-target species were identified and measured, then traps were reset. This was also done for the tau-kōura method, where baited and non-baited treatments were performed on consecutive nights.

Physical and chemical measurements

Basic water chemistry was recorded each sampling day at both Liffey Springs and Marsh Road and on four different sampling days at Northbrook. Means and standard errors for water chemistry were calculated from 10 observations at Northbrook, 23 observations at Marsh Road and 23 observations at Liffey Springs. At each reach Dissolved Oxygen (DO) and temperature measurements were recorded with a YSI 550A probe and pH and conductivity were measured using a YSI 63 probe meter. Specific conductivity was recorded with temperature adjusted to 25° C as specified in Beaumont et al. (2002). Macrophyte cover was visually assessed for approximate percentage over my 6 m sampling reaches. Stream reach and channel parameters were assessed using the channel stability score of Pfankuch (Pfankuch 1975).

Biological measurements

At each sampling site, kekewai orbit carapace lengths (OCL) were measured to the nearest millimetre using a fish measuring board. Sex and life stage were also recorded as well as any abnormalities including missing or rejuvenated chelipeds, legs, antennae and antennules. At the completion of the recordings, kekewai were released. Non-target species were identified and measured and were released after all kekewai had sufficient time to seek refuge from possible predator release. At the Northbrook site, invasive predators such as trout were removed and released into the greater Northbrook River where there is an established trout population.

Juveniles were considered to be < 20 mm OCL, which is assumed to indicate that the kekewai has had one full year of growth after hatching (Whitmore and Huryn 1999). However, this does not necessarily mean that the individuals have reached sexual maturity. It

is easier to successfully determine sex when kekewai have reached 20 mm OCL, therefore these could then be grouped into males and females. Those where sex could not be determined are in this study referred to as juveniles.

Comparisons of natural and artificial tau-kōura

Six natural tau-kōura, containing ten fronds per whakaweku and six artificial tau-kōura comprised of eight individual artificial 40 cm Christmas trees per bunch were placed in the Northbrook reach (Figure 3.7). At Northbrook, one natural and one artificial tau-kōura were placed approximately one metre either side of the station markers. Stations 1, 3 and 5 had natural tau-kōura downstream of artificial tau-kōura whereas this order was reversed for stations 2, 4 and 6.

After three weeks, natural and artificial tau-kōura at sites 2, 3 and 5 were uplifted and OCL, sex and life-stage of specimens were recorded. At the end of six weeks all remaining tau-kōura were uplifted and captured specimens were recorded. Unlike the retrieval method used in the trapping comparisons trials, whereby tau-kōura were lifted out of the water by hand, I used a modified long handled whitebait net to place the tau-kōura onto whilst it was still submerged. It was hoped that this method of retrieval would reduce the amount of kekewai escaping the tau-kōura during tau-kōura removal.

Figure 3.7. Tau- kōura constructed from artificial Christmas trees. Trees were lashed together with cable ties to increase lengths to approximately 70 cm. Four bunches were then tied together to form the tau- kōura.

Statistical analysis

Assessment of habitat parameters was conducted using a modified version of the stream reach inventory and channel stability evaluation designed by Pfankuch (1975) where reach score of <38 = Excellent, 39-76 = Good, 77-114 = Fair and 115+ = Poor. Minimum and maximum scores for Upper banks are 6 and 44 respectively. Scores for Lower banks range between 12 and 48 whilst Stream bed range is between 15 and 60. In-stream macrophyte vegetation was visually estimated for percentage of cover at each sampling site.

As data were over-dispersed, I performed quasi-poisson regression analysis using a generalised linear model (GLM) performed using library package "lme4" in "*R"* software version 3.2.4 (R Core Team 2016) to compare capture trapping efficiencies. I then conducted Tukeys post hoc tests to explain differences. Due to high variability in sample numbers chi-squared for goodness of fit (χ^2) was used to determine if any methods showed bias towards selection of sex or size. Electric fishing was used as the comparative method at each stream because analysis indicated that this method had the least bias towards size and sex.

Multiple analysis of variance (MANOVA) was used to compare mean catch per unit effort and bait conditions across all reaches. Analysis of variance (ANOVA) was used to compare catch rates between natural and artificial tau-kōura. Level of significance used for all tests was $P<0.05$.

3.3 Results

Environmental measurements

Physical stream parameters and characteristics were recorded at each site (Table 3.1). Wetted width (WW), water depth (WD) and sediment depth (DS) were measured at each sampling station along all three reaches. The mean WW for Marsh road (7.61m ± S.E 0.40), was more than double those of both Northbrook (2.00 ±S.E 0.33 m) and Liffey Springs (3.13m ± S.E 0.10). Mean WD for Northbrook (0.52m ± S.E 0.03) and Marsh Road (0.57m ± S.E 0.04) were similar, whereas Liffey Springs was more shallow (0.30m ± S.E 0.02). Mean DS was deepest at Northbrook (0.20m ± S.E 0.04) and shallowest at Marsh Road (<0.01m ± S.E <0.01) with Liffey Springs (0.01m ± S.E <0.01) falling between the two.

The results of the Pfankuch assessment between reaches ranged from “fair” to “poor” (Table 3.1). Pfankuch assessment for Northbrook scored 125 (“poor”) overall. Upper bank assessment was 32, Lower bank scored 40 and stream bed scored 53. Marsh Road scored 18 for Upper bank, 28 for Lower bank and 42 for stream bed for a total of 78 (“fair”) overall. Liffey Springs scored 89 (“fair”) overall with a score of 26 for Upper bank, 20 for Lower bank and 43 for Stream bed.

Temperatures between streams ranged from 10.1 – 12.2 °C. Mean daily temperature for Northbrook was 10.6 ±S.E 0.2, with Marsh Road being 11.5 ± SE 0.1, and Liffey Springs 11.7 ± SE <0.1. Observations of pH ranged 5.5 – 7.1 between reaches, with Northbrook having a range of 5.5 – 6.3, Marsh Road 6.0 – 7.1 and Liffey Springs 6.0 – 6.9. Mean specific conductivity for Northbrook (122 μS_{25} cm^{-1} ± SE 9.9) and Marsh Road (107μS_{25} cm^{-1} ± SE 0.4) were similar, however conductivity for Liffey Springs (221 μS_{25} cm^{-1} ± SE 1.0) was almost doubled in comparison. Total range for conductivity between reaches was 82 – 225 μS_{25} cm^{-1}. Concentrations of dissolved oxygen for Northbrook (5.8 mg/l ± SE 0.2), Marsh Road (6.4 mg/l ± SE 0.1) and Liffey Springs (5.6 mg/l ± SE <0.1) were similar however overall range was 4.6 – 7.4 mg/l between all reaches.

Table 3.1 Physical parameters for total reach length (RL), sites, distance from start (D), wetted width (WW), average water depth (WD) with range and average sediment depth (DS) with range, percentage of macrophyte cover (M) and reach Pfankuch score (Pf). Physical parameters were taken on the first day of sampling and chemistry measurements were recorded throughout the sampling period. Dates that chemistry was recorded is shown for each reach, with means and range (in brackets) for temperature (T), pH, Specific conductivity (μS_{25} cm^{-1}) and Dissolved Oxygen (DO).

Reach	S	D	WW (m)	Ave. WD (m)	Ave. DS (m)	M (%)	Pf Score	Chemistry
Northbrook	1	0	2.8	0.54 0.26 – 0.80	0.47 0.20 – 0.62	80	125	Dates 24/5 – 10/6
RL 85 (m)	2	17	2.3	0.57 0.52 – 0.60	0.17 0.10 – 0.25	75		**T** 10.7 (10.1 – 11.8)
	3	28	1.2	0.46 0.22 –0.64	0.12 0 – 0.23	20		**pH** (5.5 –6.3)
	4	43	1.0	0.55 0.47 – 0.64	0.55 0.20 – 0.10	0		**μS_{25} cm^{-1}** 122 (82 –167)
	5	60	1.7	0.52 0.52 – 0.53	0.30 0.26 – 0.39	20		**DO** 5.8 (4.6 – 6.9)
	6	85	3.0	0.47 0.33 – 0.57	0.10 0.40 – 0.21	10		
Marsh Road	1	0	10.2	0.60 0.39 – 0.84	0.19 0 – 0.49	30	88	Dates 8/6 – 15/7
RL 88 (m)	2	14	10.0	0.53 0.15 – 0.74	0.66 0 – 0.80	40		**T** 11.5 (10.2 – 12.1)
	3	36	9.0	0.53 0.38 – 0.72	0.28 0 – 0.11	40		**pH** (6.0 –7.1)
	4	48	5.0	0.57 0.18 – 0.85	0.81 0 – 0.21	60		**μS_{25} cm^{-1}** 107 (106 – 116)
	5	65	6	0.53 0.34 – 0.84	0.12 0 – 0.28	50		**DO** 6.4 (5.0 – 7.4)
	6	88	5.3	0.65 0.25 – 0.89	0.34 0 – 0.15	30		
Liffey Springs	1	0	4	0.30 0.15 – 0.50	0.31 0.21 – 0.41	90	89	Dates 25/6 – 5/7
RL 100 (m)	2	20	3.1	0.41 0.32 – 0.49	0.12 0 – 0.19	70		**T** 11.7 (10.9 – 12.2)
	3	40	3.7	0.35 0.19 – 0.51	0.16 0.07 – 0.39	55		**pH** (6.0 – 6.9)
	4	60	2.4	0.27 0.09 – 35	0.10 0 – 0.27	60		**μS_{25} cm^{-1}** 221 (200 –225)
	5	80	2.9	0.24 0.07 – 0.32	0.07 0.03 – 0.19	45		**DO** 5.6 (4.7 – 6.2)
	6	100	2.7	0.26 0.06 – 0.49	0.11 0.01 – 0.29	65		

Trapping methods

Numbers of kekewai caught differed between methods and reaches (Figure 3.8). Multiple linear regression analysis showed there were significant differences between capture methods ($F_{6,12}$ = 7.08, P < 0.01), however it also showed that the effect between sites ($F_{2,18}$ = 16.57, P < 0.01) was also significant. After accounting for reach variation, capture rates in Northbrook were significantly higher for electric fishing compared to the other capture methods. Tukeys post hoc showed that electric fishing caught significantly more kekewai than fyke nets (z =3.27, *P*= 0.01), un-baited gee-minnow (z =2.89, *P*= 0.05), spotlight and hand net (z =3.27, *P*= 0.01) baited tau-kōura (z =3.28, *P*= 0.01) and un-baited tau-kōura (z =3.03, *P*= 0.03). Capture rates between passive trapping methods were similar in all three reaches. Although more kekewai were caught using electric fishing in both Liffey Springs and Marsh Road compared to the other capture methods, they were not significantly different.

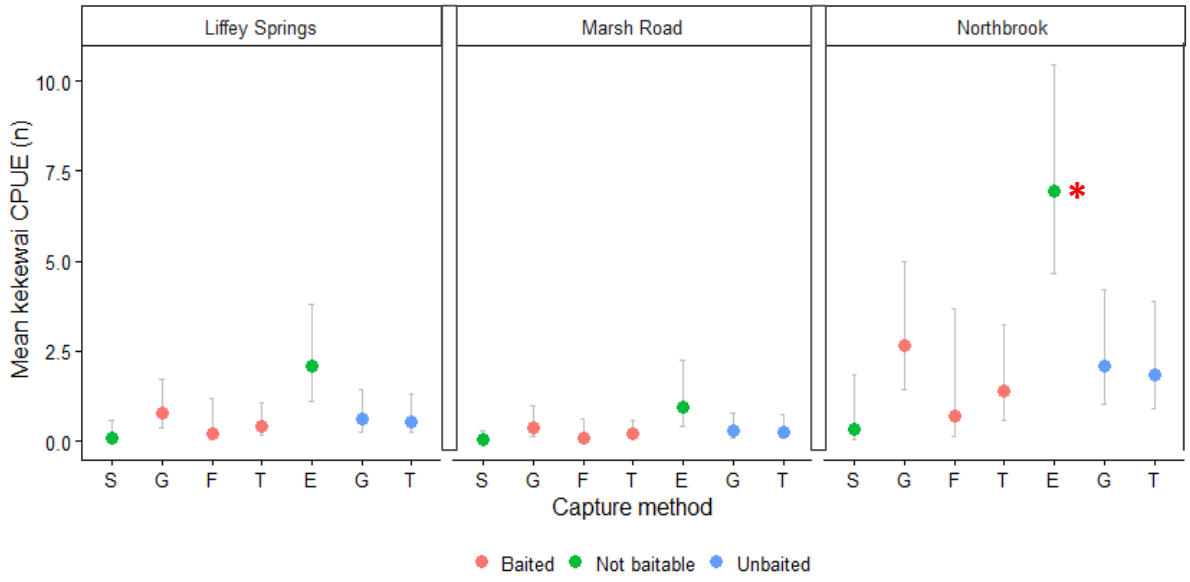

Figure 3.8 Mean Catch per Unit Effort (CPUE with 95% confidence intervals) for spotlight and hand-net capture (S), fyke nets (F), gee-minnows (G), tau-kōura (T) and electric fishing (E). Colours indicate whether capture methods were baited, un-baited or not-baitable. Significance is indicated with a *

The size of kekewai captured varied with each sampling method (Figure 3.9). For both baited and un-baited gee-minnow passive trapping in Northbrook there was bias towards larger individuals, whereas baited and un-baited tau-kōura attracted smaller kekewai. Fyke nets caught only 3 large kekewai in Northbrook. Due to low catch rates, size differences between passive trapping methods could not be accurately assessed in Marsh Road and Liffey

Springs. Active capture methods did not appear to show any bias for size (Figure 3.10). Electric fishing captured similar size classes in all three reaches.

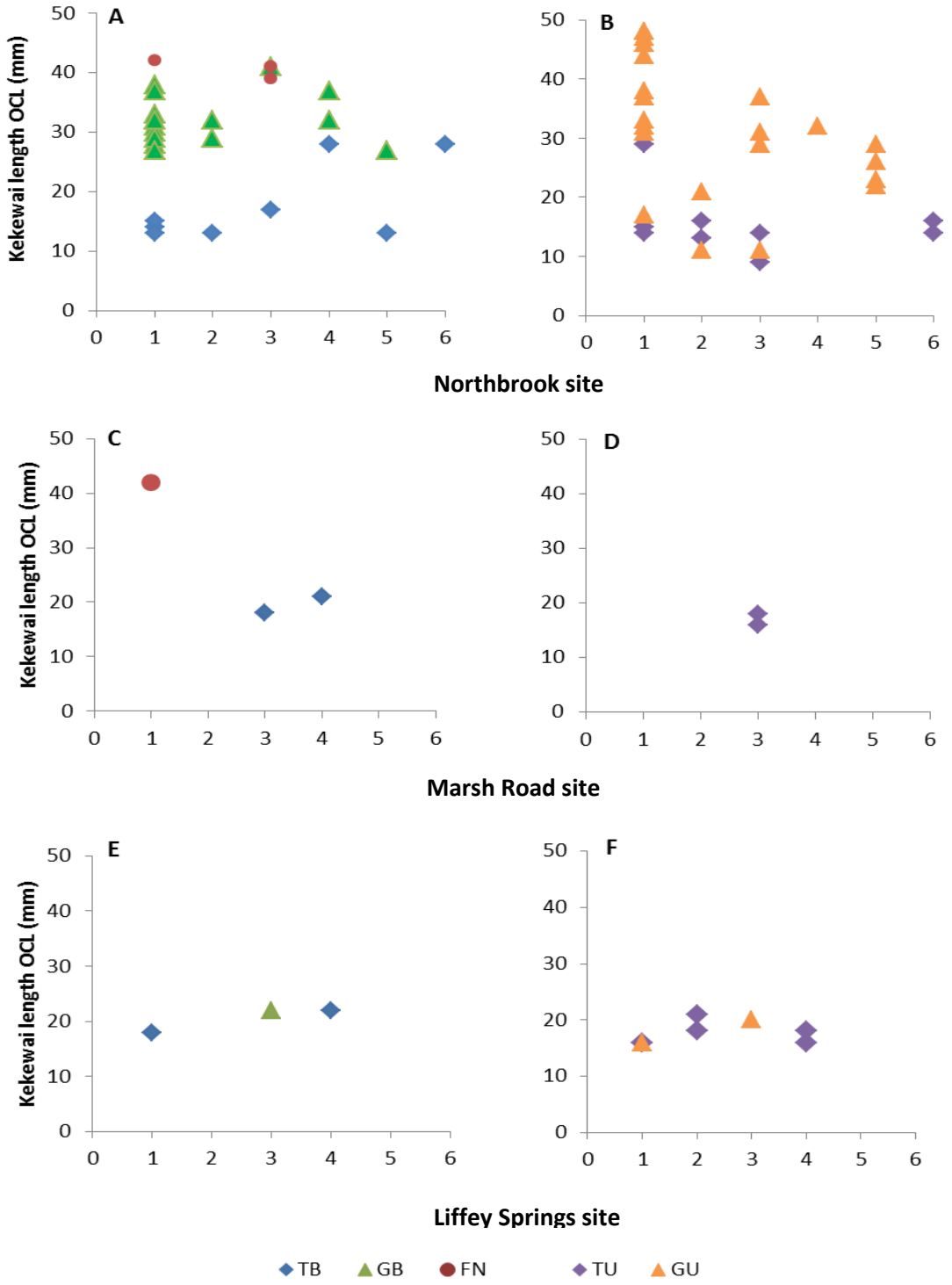

Figure 3.9 Orbit Carapace Length (OCL) of kekewai caught at the six sampling stations (1-6) at Northbrook, Marsh Road and Liffey Springs passive trapping types. Baited traps (A,C,E) are shown on the left and un-baited traps (B,D,F) are shown on the right. Station 1 is situated the furthest downstream. Legend key is baited taukoura (TB), baited gee-minnow (GB), fyke net (FN), un-baited tau-koura (UB) and un-baited gee-minnow (UB).

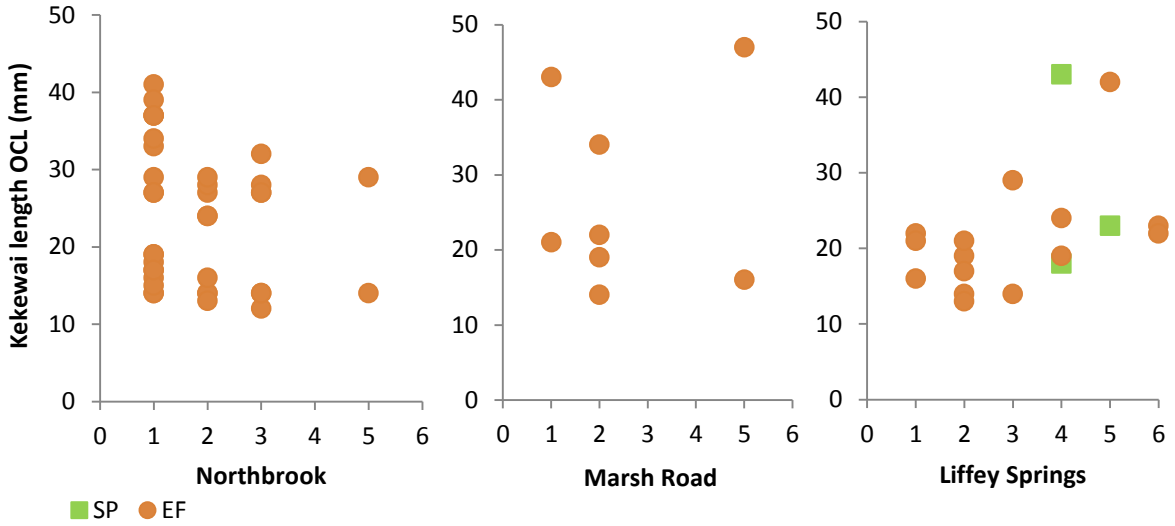

Figure 3.10 Size distribution of kekewai caught in all three sites using active fishing techniques spotlight and hand net capture (SP) and electric fishing (EF). Station 1 is situated furthest downstream.

Active fishing methods

Of all methods trialled, electric fishing showed no bias for sex and size and therefore sampled the most representative of populations in my reaches (Table 3.2 Appendix A). Electric fishing had the highest mean CPUE for combined sites across all reaches (3.33 ± S.E 1.09). Northbrook had the highest mean CPUE (6.17 ± S.E 2.99) with Marsh Road having the lowest (1.33 ± S.E 0.67). Mean CPUE for Liffey Springs was (2.50 ± S.E 0.56). There were no differences for numbers of males and females caught at Northbrook ($F_{1,6}$ = 0., P =0.40) and numbers of juveniles (less than 20 mm) and adults captured were also similar ($F_{1,6}$ = 0.13, P =0.70) (Figure 3.11). Sex ratios for Liffey Springs were also similar ($F_{1,10}$ = 4.0, P =0.07), as were adults and juveniles ($F_{1,10}$ = 0.05, P =0.80).

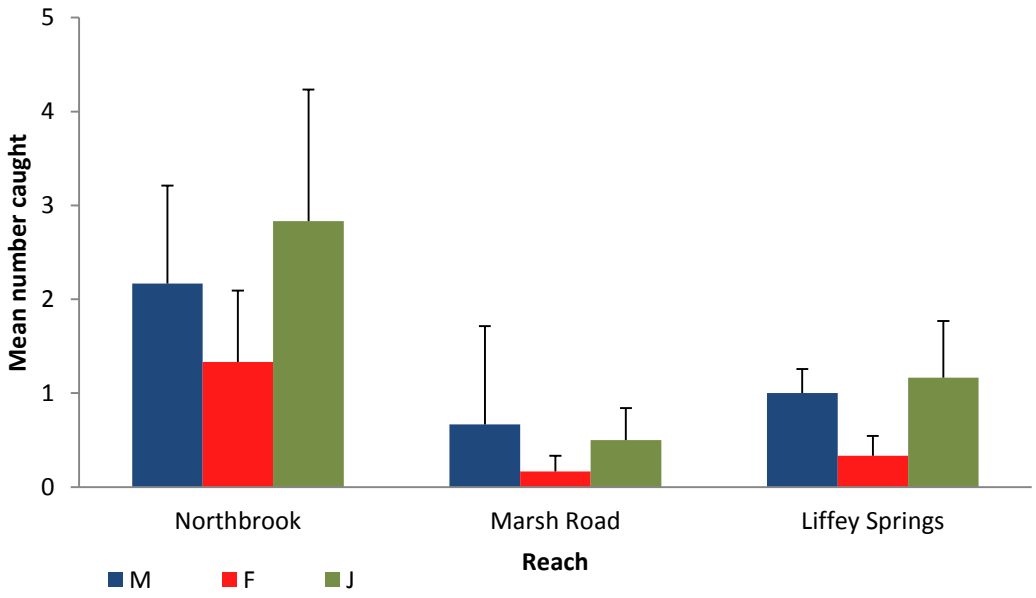

Figure 3.11 Mean (+ 1 SE) number of males (M), females (F) and juveniles (J) captured by electric fishing at all three reaches.

Non-target species caught at Northbrook using electric fishing were common bullies and upland bullies; however they were not collected and recorded. Marsh Road caught no non-target species during electric fishing. Non-target species caught at Liffey Springs were 12 common bullies, 13 upland bullies and 2 inanga (*Galaxias maculatus*).

Spotlight and hand net capture was unsuccessful for kekewai capture in both Northbrook and Marsh Road reaches. In Liffey Springs, three kekewai were caught in two sites. Macrophyte growth and disturbed sedimentation reduced detectability of specimens in all reaches. Some specimens that were detected were able to evade capture by retreating into macrophyte cover. Non-target species were observed in all reaches but were not caught.

Passive fishing methods

For gee-minnow trapping, there was no difference between baited and unbaited traps the mean CPUE for all reaches combined were 1.20 ± S.E 0.65 for baited traps and 1.00 ± S.E 0.50 for un-baited (Figure 3.12)($F_{1,38}$ = 0.20, P =0.65). The most specimens caught in Northbrook with gee-minnow traps (baited mean CPUE 3.67 ± S.E 1.60 and un-baited 2.67 ± S.E 1.50).

For baited gee-minnow traps in Northbrook, the ratio of adults to juveniles (< 20 mm OCL) caught was significantly different than expected χ^2 (1, N = 16) = 5.89, P< 0.05 as was un-baited gee-minnows χ^2 (1, N = 17) = 4.40, P< 0.05. This confirms bias for gee-minnow traps towards larger individuals, however no adults were captured in either baited or un-baited gee-minnow traps at Liffey Springs. The ratio of males to females was again similar to electric fishing for both baited gee-minnow traps χ^2 (1, N = 16) = 0.45, P> 0.05 and un-baited gee-minnows χ^2 (1, N = 17) = 0.64, P>0.05 for Northbrook. (Figure 3.13).

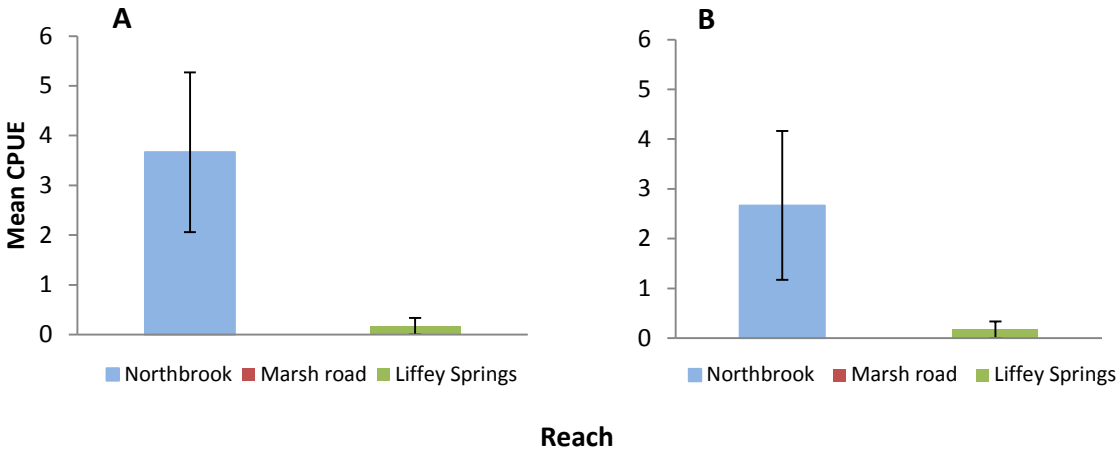

Figure 3.12 Mean (± 1 SE) for baited gee-minnow (A) and un-baited gee-minnow (B) trapping at all three reaches. Total numbers caught were NB Gee-minnow traps were unsuccessful at capturing kekewai in Marsh road

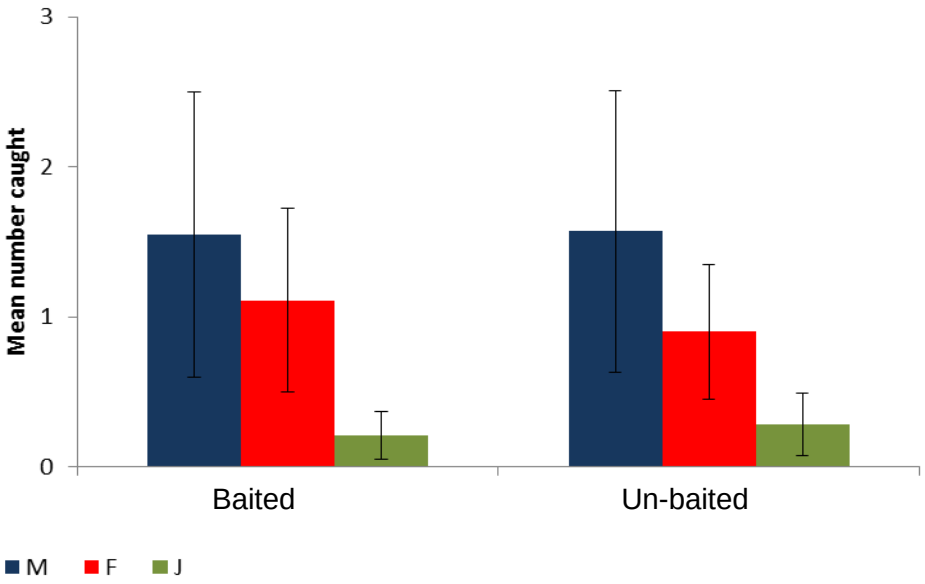

Figure 3.13 Mean number (±S.E) of males (M), females (F) and juveniles (J) caught in baited (n=6) and un-baited (n=7) gee-minnow traps. Numbers are for successful traps in combined Northbrook and Liffey Springs sites.

There were no non-target species caught at the Northbrook reach. At Marsh Road, non-target species captured included 1 giant bully (*Gobiomorphus gobioides*), 1 common bully (*Gobiomorphus cotidianus*), 1 upland bully (*Gobiomorphus breviceps*) and 1 long fin eel (*Anguilla dieffenbachii*) in baited traps and 3 giant bullies and 5 common bullies in the un-baited traps. Non-target species captured at Liffey Springs in the baited condition were 3 upland bullies and 4 common bullies whilst un-baited traps caught 2 upland bullies, 5 common bullies and 1 giant bully.

Kekewai were captured in both baited and un-baited gee-minnow traps. No kekewai were caught in gee-minnow traps at Marsh Road. At Liffey Springs, one kekewai was caught with bait and two were caught without bait.

Fyke nets were deployed once at three sites in each reach. They were the least successful passive trap method with a total of three specimens caught from the nine sites that they were deployed. Two specimens were captured at the Northbrook reach, one male and one female in the same fyke and one male specimen was captured at Marsh Road reach. All three kekewai captured were large adults. At Liffey Springs, one longfin eel was captured.

Traditional methods

Tau-kōura attracted kekewai at all three streams, however catch rates were low. Combined reach mean CPUE for baited tau-kōura trapping was 0.66 ± S.E 0.18 and un-baited tau-kōura was 0.94 ± S.E 0.25 (Figure 3.14). Northbrook had the highest mean CPUE (1.33 ± S.E 0.33) for baited tau-kōura and un-baited tau-kōura (1.50 ± S.E 0.50). Mean CPUE of baited tau-kōura at Marsh Road (0.33 ± S.E 0.21) was similar to that for un-baited tau-kōura (0.50 ± S.E 0.34). At Liffey Springs the mean CPUE for baited tau-kōura (0.33 ± S.E 0.21) and un-baited tau-kōura were similar (0.83 ± S.E 0.40).

Numbers of kekewai caught using tau-kōura were low in both baited and un-baited traps at all three reaches and there were no significant differences for kekewai capture between baited and un-baited tau-kōura ($F_{1,34}$ = 0.81, P =0.37). No males were caught in baited tau-kōura at Northbrook or Marsh Road and only one male was captured at Liffey Springs. Un-baited tau-kōura did not capture any males at any of the reaches. The ratio of adult to juvenile catches at Northbrook were similar to that of electric fishing χ^2 (1, N = 8) = 2.90, P< 0.05 for baited tau-kōura, however there were significantly more juveniles caught

than adults in un-baited tau-kōura χ^2 (1, N = 10) = 8.18, P< 0.05 (Figure 3.14). There were insufficient numbers caught at Marsh road and Liffey Springs to assess ratio of adults to juveniles. Liffey Springs was the only reach where tau-kōura caught non-target species which included 4 common bullies and 3 upland bullies. Non-target species were only present in baited tau-kōura.

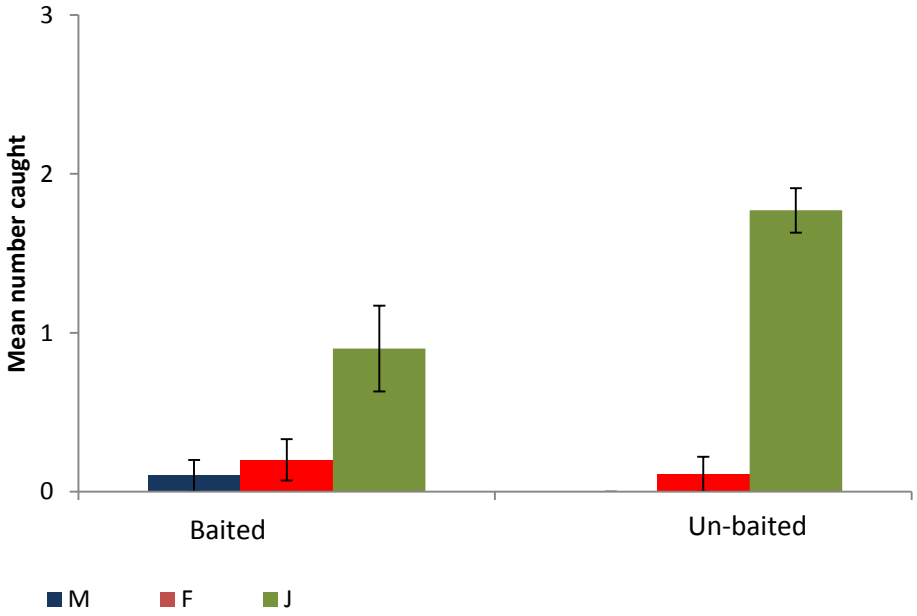

Figure 3.14 Mean number (±S.E) of males (M), females (F) and juveniles (J) caught in baited (n= 10) and un-baited (n=9) for tau-kōura traps. Numbers are taken from successful traps across all sites combined.

The biomass of tau-kōura did not show any correlation with numbers of kekewai caught (Figure 3.15). Mean dry weights of tau-kōura deployed at Northbrook (0.55 ± S.E 0.02) and Marsh Road (0.56 ± S.E 0.02) were similar. Although tau-kōura at Liffey Springs (0.89 ± S.E 0.03) had a greater mean biomass, this did not appear to promote or impede kekewai capture.

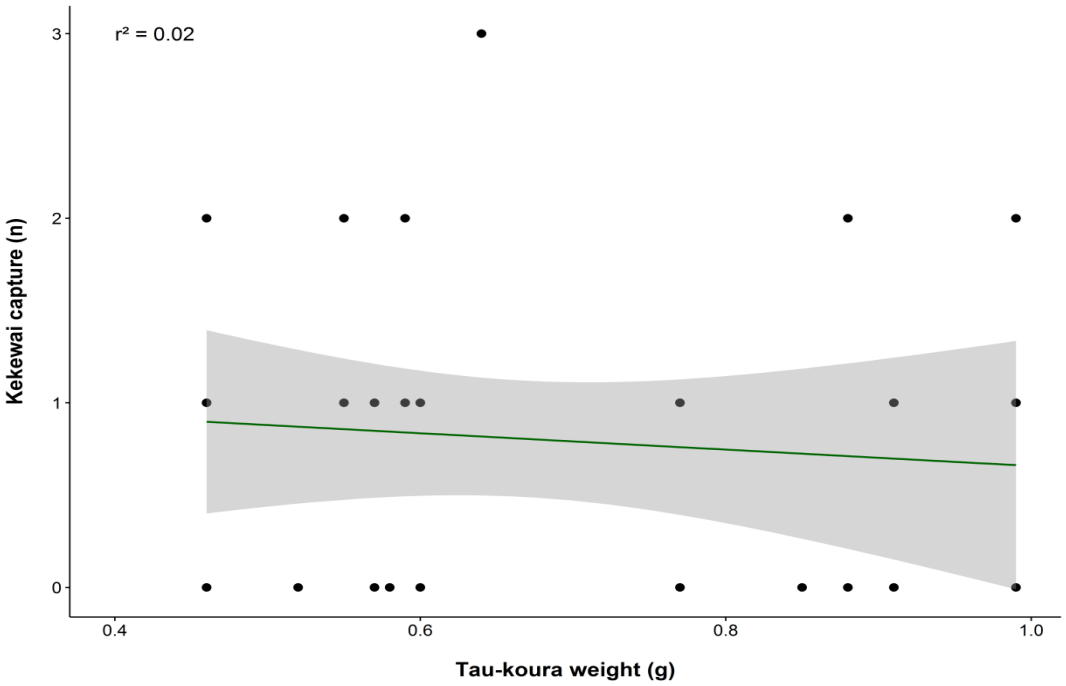

Figure 3.15 Total number of kekewai caught in combined baited and un-baited conditions and tau-kōura biomass.

Artificial and natural tau-kōura

Over the course of the experiment biomass of tau-kōura increased with the addition of organic debris. (Table 3.3). Organic debris was deposited and became intertwined with the traps in both natural and artificial tau-kōura.

Table 3.3 Pre deployment weights (PW) and post deployment dry weights (DW) of both artificial and natural tau-kōura. Pre-deployment weights of natural tau-kōura are wet weights. As N1 was removed from the study area there is no recorded DW and is therefore shown as a (-). All tau-kōura were deployed on the 15/11/2015.

Date Uplifted	Artificial tau-kōura	PW (kg)	DW (kg)	Natural tau-kōura	PW (kg)	DW (kg)
5/12/2015	A2	0.58	0.63	N2	1.09	0.50
5/12/2015	A3	0.59	0.62	N3	1.06	0.44
5/12/2015	A5	0.58	0.65	N5	0.79	0.34
26/12/2015	A1	0.59	0.61	N1	0.91	-
26/12/2015	A4	0.59	0.64	N4	0.8	0.31
26/12/2015	A6	0.58	0.62	N6	1.09	0.55

Kekewai used both natural and artificial tau-kōura for both 3 week and 6 week deployments. Mean CPUE in artificial tau-kōura for 3 weeks was 2.33 ± S.E 1.45 and 2.00 ± S.E 1.15 after six weeks (Figure 3.16). For natural tau-kōura, mean CPUE after 3 weeks was 5.66 ± S.E 1.76. and 5.00 ± S.E 1.00 after six weeks. Natural tau-kōura had a higher capture rate than artificial tau-kōura for combined 3 week and 6 week totals ($F_{1,9}$= 6.10, P=0.03), despite outside interference with one of the natural tau-kōura being removed from the study area. Kekewai life stage was also significantly different ($F_{2,23}$= 36.88, P<0.01). There were significantly more juveniles than males Tukeys post hoc (P< 0.01) and more juveniles than females (P< 0.01), however numbers of males and females were similar (P= 0.8) as shown in Figure 3.17.

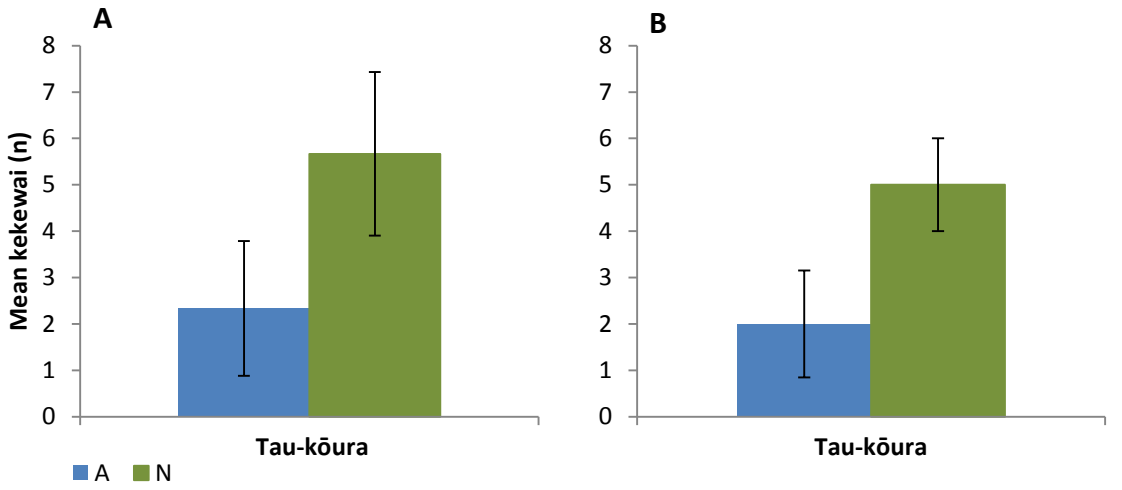

Figure 3.16 Mean (± S.E**)** number of kekewai in natural and artificial tau-kōura after 3 weeks (A) and 6 weeks (B).

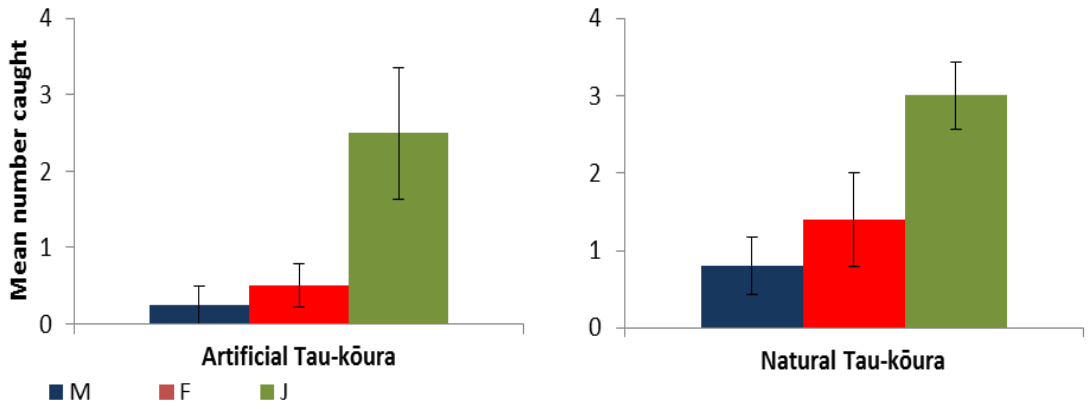

Figure 3.17 Mean (± S.E) for number of males (M), females (F) and juveniles (J) caught in artificial and natural tau-kōura

3.5 Discussion

My study confirms that Canterbury kekewai can be captured using a variety of techniques but the efficiency of capture varies with location and methodology. The most successful method in this study was electric fishing which captured the highest number of kekewai in all three streams, however catch rates were only statistically significant in the Northbrook stream. This could be due to low densities of kekewai that contributed to the low capture rates for every method in Marsh Road and Liffey Springs. Electric fishing showed no biases for size or sex which is in keeping with other studies (Alonso 2001, Price and Welch 2009). Although it was the most effective method overall, electric fishing was also the most intrusive. At many of the sites, macrophytes were uprooted and became ensnared in the push nets during electric fishing. Kekewai that had sought refugia within macrophyte growth were then captured due to the dredging motion of the push nets which may have contributed to the higher capture rate using this method.

When using electric fishing to sample crayfish or other fishes, often a multiple-pass depletion method is used to improve accuracy of population assessments (Meador et al. 2003). This involves multiple passes of the same area to insure that the majority of individuals present are counted (Rabeni et al. 1997, Usio and Townsend 2001). However, single pass electric fishing greatly improves species detection with decreasing stream width (Meador et al. 2003). Because streams in the present study were relatively narrow (< 11 m), the single pass technique most likely gave a representative account of population structure and abundance.

Although electric fishing is considered to be one of the most effective methods for sampling fish populations, its use is limited to shallow waters (Alonso 2001, Price and Welch 2009). Westman et al. in Price and Welch (2009) agreed with this but also said that it was biased against the smallest crayfish within populations and was difficult to use in and around vegetated areas. Although I concur that it is difficult to use in areas where there are dense patches of macrophyte growth, I found no bias against smaller crayfish. This may however, be because many smaller individuals sought refuge within macrophytes and were then dislodged when they were disturbed. Gladman et al. (2010) compared electric fishing to other active methods and found electric fishing to be far more effective at sampling crayfish populations, especially in colder months. This was also the case in the present study.

In contrast to electric fishing, spotlighting (and hand netting) was perhaps the most ineffective method for kekewai capture I trialled in the study streams. Only Liffey Springs yielded results for hand net capture, whilst kekewai in Northbrook and Marsh Road were rarely detected. This could be attributed to the fact that visual detection was impeded by high macrophyte cover and sediment disturbance. When Rabeni et al (1997) compared hand netting with electric fishing and quadrat sampling to capture *P. planifrons* in a Ngāruawāhia forest stream, they found hand netting captured a higher number of larger individuals. They proposed that this could be due either to larger crayfish being more exposed and active at night or that they were more readily observed at night. This did not appear to be the case in my study, however there are other differences between our studies to consider including that Rabeni et al (1997) replicated their study over a series of nights whereas I had a single night's observations. Also the Rabeni et al. (1997) study was conducted over the summer, the season when crayfish are believed to be more active, whereas in the present study sampling was carried out over late autumn and early winter. There is also the possibility that by chance, the nights randomly selected for spotlighting and hand netting were also nights when the crayfish were not as active.

Gladman et al. (2010) found that in comparison to other active fishing methods, hand netting was an inefficient technique and was unsuccessful at capturing crayfish in more than 50% of the 25 sites that had confirmed crayfish presence. Similar to the present study, Gladman et al. (2010) conducted their experiments over the cooler months. They proposed that this would help to determine which technique was the most sensitive in detecting crayfish. Although I agree with this logic, I also believe that crayfish abundance is density dependent and high density populations may show a more favourable result towards methods that might normally be considered not so efficient and if this is the case, then the opposite could also be true.

Passive trapping

Passive trapping showed differing results, with gee-minnow traps capturing large individuals and tau-kōura attracting a higher proportion of smaller individuals. Although this was expected for gee-minnow performance, it was not what was expected for tau-kōura. Fyke nets were not as successful as I had expected.

Fyke nets which are considered to be one of the most effective trapping methods for crayfish harvest overseas (Balık et al. 2003) performed poorly in the streams. Balık et al

(2003) investigated trapping efficiency of un-baited and baited fyke nets, they found that catch rates were similar for baited and un-baited conditions, however one bait type (bread) did attract more crayfish than the others. Of the four different bait types they trialled including apple, Prussian carp, potato and bread, only bread was significantly different (Balık et al. 2003). As the bait I used was successful for the other passive trap types I trialled, it is unlikely that bait choice would have negatively affected my catch rates. The fyke together with the leader net used in the present study more than doubled the sampling area than the other trap types. This might be expected to increase the likelihood of kekewai capture. Unfortunately this was not the case in the streams I was sampling.

The low numbers caught with fyke nets cannot be attributed to the sites within streams where they were placed as other passive trapping types successfully captured kekewai in the same sites. Freeman et al. (2010) suggests that fyke nets are only suitable for trapping crayfish in still water environments. This may be an important aspect in the present study where all of the streams are flowing waters. In addition, fyke nets captured the largest predatory fish, a native eel (*Anguilla dieffenbachii*), which may have affected the numbers of kekewai caught in Liffey Springs. For example, if kekewai had ventured into the fyke net, they may have been consumed before I was able to retrieve the net. Unfortunately, at Liffey Springs, some of the fyke nets had been interfered with prior to my return. This was evident in the change of positioning when I went to retrieve them, so therefore I cannot rule out their effectiveness in this stream.

In Northbrook gee-minnow trapping favoured large kekewai individuals, however the proportion of males to females was not significantly different. This agrees with Acosta and Perry (2000) who found no differences between sexes unlike other studies that found gee-minnow trapping favoured large males (Capelli and Magnuson 1983, Somers and Stechey 1986). Silbey (2000) used "trappies," for removal of signal crayfish at the River Stour in Wixoe. These traps were designed for sustainable crayfish harvesting in mainland Europe, and are similar to gee-minnow traps with the exception being that they have extra holes that will allow for the escape of smaller individuals (< 40 mm CL). Even when populations were predominantly females, the captured specimens were highly biased towards males (Sibley 2000). This observation highlights how biased capture methods can potentially be misleading for assessment of population dynamics within stream systems. It is worthy to note that gee-minnow traps have also been known to be highly selective and have shown strong bias when sampling other types of fishes (Hayes 1989, Layman and Smith 2001). Layman and Smith

(2001) found that gee-minnow traps consistently favoured one resident fish species whilst being biased against other resident fishes. Baited gee-minnow traps in the present study were biased towards large kekewai with only adults (OCL > 20 mm), being caught. However, un-baited gee-minnow traps caught both the largest (OCL =48 mm) and the smallest (OCL =11 mm) specimens.

Dupuch et al (2011), conducted experiments in Canada to determine if predation risk and habitat complexity affected gee-minnow trapping of three species of prey fishes. They proposed that prey fishes would be less likely to be attracted to traps as a source of refugia in habitats that could provide alternate sources of refuge. They found that dense vegetation negatively affected gee-minnow attractiveness to prey fishes, and that increased predation risk also reduced trap efficiency for one of the prey species. This did not appear to be the case in the present study as the streams contained areas of dense vegetation and both kekewai and predatory fishes were present in gee-minnow traps. As most of the predatory fishes caught in the gee-minnow traps were small, it is unlikely that they would have consumed kekewai already in the traps. It is not known however, if kekewai entered the traps before or after predatory fishes, therefore it is also unknown if predatory fishes were more attracted to the gee-minnows because kekewai were present. As predatory fishes were also present in un-baited gee-minnow traps, we can conclude that bait may not be the attractant.

Tau-kōura were the only passive traps trialled that caught kekewai in all three streams, however numbers of kekewai caught were low. In contrast to gee-minnow trapping, tau-kōura tended to select for smaller individuals and of larger kekewai caught only one was male. This was not as expected, as previous studies conducted by Kusabs and Quinn (2009), found that tau-kōura was less biased towards size or sex than other trapping methods.

Crayfish harvesting usually occurs when the tau-kōura have been deployed for some time, approximately 4 – 12 weeks (Kusabs and Quinn 2009). However, in the present study tau-kōura were only in-situ for a 24 h period, this might explain the low numbers of kekewai captured compared to gee-minnow trapping. The tau-kōura retrieval technique that I employed may have also contributed to the low numbers of kekewai caught. Kusabs and Quinn (2009), placed a kōrapa (traditional net woven from flax) underneath the tau-kōura before lifting it from the water. This was to ensure that crayfish did not escape before they could be retrieved from the tau-kōura.

The uplifting of overnight tau-kōura in Northland does not usually require a net to harvest crayfish, it is believed that the crayfish use their chelipeds to attach themselves to the fern fronds (Pohe, pers. coms). This combined with quick handling and retrieval can ensure that no crayfish are lost. Although this might be the case for crayfish in Northland, my personal observations were that some kekewai did detach themselves before the tau-kōura were successfully retrieved. Tau-kōura are very heavy when they have been submerged and retrieval can be difficult, this might have also contributed to the low numbers of kekewai caught.

Site variation

Kekewai capture was successful for at least one method at all of the sites at each stream reach, with the exception being one site at Marsh Road. Numbers of kekewai caught in all the methods I trialled were relatively low. Factors that could have contributed to this include overall low-density populations, season and time of sampling, changes in habitat and land use modification. Both Northbrook and Liffey Springs are situated in rural areas that were previously dominated by agricultural land use, however there has been recent property development. Northbrook and Marsh Road are part of the same catchment, but Marsh Road is still productive farmland. Marsh Road had the lowest number of kekewai caught of all the streams (n= 20), which was surprising as Marsh Road had the highest number of observed kekewai during the initial survey (Chapter 2). Property development has been occurring for longer in Northbrook than in Liffey Springs, where habitat assessments of stream reach inventory and channel stability suggest that environmental conditions were relatively good.

Artificial and natural tau-kōura

As natural tau-kōura attracted significantly more kekewai than artificial tau-kōura, we can assume that other aspects apart from refugia contributed to tau-kōura attractiveness. These could include factors such as the potential food resources that natural tau-kōura are able to provide. These resources could be in the form of the vegetative matter that the tau-kōura is comprised of, or potentially invertebrate prey that could also be using the tau-kōura as refugia or food source.

All natural tau-kōura uplifted were successful for attracting kekewai, whereas only four out of six of the artificial tau-kōura attracted kekewai. Numbers of individuals caught with natural tau-kōura ($\bar{x}$ = 5.1) were double those of artificial tau-kōura ($\bar{x}$ = 2.1). This

difference indicates that refugia by itself is not the main reason for kekewai to use tau-kōura. It may suggest that kekewai use this as a potential food source. The size distribution of caught individuals was the same for both natural and artificial tau-kōura ranging from small juveniles (OCL length 3 – 10 mm) to adults (OCL length 20 – 34 mm). Natural tau-kōura caught both the largest (female 34 mm) and smallest (3 mm) specimens. The progeny of *Paranephrops* spp., in particular *P. zelandicus* can remain closely associated with their mother for up to two years after hatching (Whitmore and Huryn 1999), therefore with the capture of small juveniles, we would expect to see sexually mature females, however, this was not the case in the present study.

When freshly cut, the fern fronds that are used to construct tau-kōura are much heavier than their artificial counterparts. This is because the natural tau-kōura contain moisture whereas the artificial do not. Shaking to remove excess debris after tau-kōura had been uplifted resulted in artificial tau-kōura losing most of the excess debris without affecting the original biomass, unlike natural tau-kōura which lost a small portion of original fern biomass but did not lose all of the excess debris. Natural fern biomass loss was mostly from the tips of the fronds and would probably be a similar weight as the debris retention. When both natural and artificial were uplifted and dried their biomasses were similar. Therefore differences in biomass may not be an important factor affecting catch rates of kekewai in natural and artificial tau-kōura.

In conclusion, to ascertain abundance and population structure of kekewai and other crayfishes in waterways, requires knowledge of efficiencies and limitations of sampling methods and techniques. This is particularly important when working with low-density populations as it is easier to achieve a particular level of precision when population densities or abundances are high (Rabeni et al. 1997). Understanding bias and selectivity in various capture methods could aid in developing sampling regimes that portray a more accurate representation of population dynamics. This knowledge is also useful if information about a particular cohort is required, as it could be adapted to specifically select for the cohort of interest.

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Laboratory feeding trials for *Paranephrops zealandicus*

4.1 Introduction

Freshwater crayfish are considered opportunistic omnivores that will eat a variety of vegetation, detritus, invertebrates and small animal prey. Previous studies have shown crayfish consume vegetative matter (Parkyn et al. 2001, Hollows et al. 2002, Bondar et al. 2005, Price and Welch 2009, Vehanen et al. 2013), however, protein is an important component of their diet for growth and development (Parkyn et al. 2001, Hollows et al. 2002). Freshwater crayfish feed on a variety of invertebrates but have also been known to prey on eggs and young of other aquatic species such as fishes (Hobbs et al. 1989) and frogs (Nyström and Åbjörnsson 2000). There have been several studies investigating the diet of the New Zealand freshwater crayfish and crayfish are often found in the presence of macrophytes but little research has been conducted on macrophyte consumption and dietary preference.

In New Zealand, native crayfish are the largest freshwater organisms that process detritus and aquatic vegetation. They break down macrophytes and coarse particulate matter that can then be assimilated by smaller invertebrates. The ability of crayfish to effectively process detritus can potentially influence stream community dynamics (Hollows et al. 2002). Crayfish also play a crucial role as bioengineers by moving sediment, this aids in creating habitats for other species as well as contributing to the maintenance of stream health.

Studies have shown that crayfish can consume approximately 1.3 – 1.4% of their body weight per day (Loya-Javellana et al. 1995), however when food is abundant they have been known to increase their food intake (Carral et al. 2011). The total amount a crayfish can consume is dictated by the size of the foregut (Loya-Javellana et al. 1995). Research into the diet of juvenile astacid crayfish conducted by Carral et al. (2011) found that excessive feeding can be as much as 2.5% of bodyweight per day. However, Momot et al. (1978) cites a study conducted by Orzechowski (1973), which found that with the species *Orconectes limosus*, large crayfish can consume as much as 50% and smaller crayfish 7% of their bodyweight per day.

Previous studies on crayfish diet

Previous studies investigating the effects of crayfish herbivory on macrophyte species have been contradictory. Chambers et al. (1990) found that the crayfish *Orconectes virilise* in Alberta, Canada, had a significant impact on the biomass of submerged plant species. These findings were supported by another study by Sato et al. (2014) in Iwata, Shizuoka prefecture, Japan, which found that the introduced crayfish *Procambarus clarkii* consumed large amounts of macrophytes to the extent that they were heavily diminished. In contrast, research conducted by Hessen et al. (2004) on Lake Steinsfjorden, Norway found that the growth of some submerged macrophytes far exceeded the amount that some crayfish species could consume. This was reported to negatively affect crayfish distribution and abundance due to excessive macrophyte growth which resulted in changes in habitat (Hessen et al. 2004). Hessen et al (2004), speculated that the dense stands of *Elodea canadensis* might inhibit the movement of adult crayfish, and that strong fluctuations in pH and O_2 recorded within these stands could act as a potential stress factor. Although in New Zealand there has been some research on *P. zealandicus* consumption of *E. canadensis* in Lake Georgina (Musgrove 1988), there is still very little known about whether kekewai could be effective herbivores of other invasive macrophytes. The majority of studies on the feeding behaviours of New Zealand crayfish have shown detritus and invertebrates to be the main dietary constituent (Momot et al. 1978, Parkyn et al. 1997, Usio 2000, Hollows et al. 2002).

The majority of detritus in headwater streams is of allochthonous, terrestrial origin (Vannote et al. 1980). Detritus appears to be the main food in crayfish guts. There have been several studies locally and overseas that have found detritus accounts for the greatest volume of material in crayfish gut and stomach analyses (Hollows et al. 2002, Stenroth and Nyström 2003, Bondar et al. 2005). Many observations of foraging behaviour and the effects that crayfish have on in-stream processes reinforce the importance of detritus in diets (Creed and Reed 2004, Zhang et al. 2004). However, other studies have found that the amount of detritus consumed by crayfish depends on habitat (Parkyn et al. 2001), and that crayfish can flourish in streams with little allochthonous, terrestrial input. Although generally detritus may be a significant constituent of crayfish diets it may not necessarily be the most nutritious. Jones and Momot (1983) cited in Creed (1994), found that crayfish grew faster on a diet of filamentous algae than they did on detritus. Detritus is commonly reported as a component of crayfish diets, however, it is often described under as allocthonous terrestrial input or leaf

litter. There appears to be very little literature describing the type of terrestrial vegetation the detritus is made up of, such as dicotyledon, monocotyledon, deciduous and/or evergreen.

Despite the fact that many analyses of gut and stomach contents have mostly been dominated by detritus, much of it may not be incorporated into crayfish tissue (Parkyn et al. 2001). However, invertebrates can also be an important food for crayfish diets for growth and development (Parkyn et al. 2001, Hollows et al. 2002). This has been further supported from stable isotope analyses of $\delta^{13}C$ and $\delta^{15}N$ have shown that invertebrates contribute to crayfish tissue (Hollows et al. 2002). These findings support other studies that indicate the diet of juvenile crayfish is predominantly rich in animal proteins (Geiger et al. 2005) and is often comprised mainly of invertebrates and zooplankton (Whitmore et al. 2000, Stenroth et al. 2006). Parkyn et al (2001) found that crayfish in pasture streams consume more invertebrate prey than crayfish in forested streams, whereas Hollows et al (2002) found no differences in invertebrate consumption between bush and pasture streams. This difference may be a reflection of availability of different food items.

Rationale for study

Within Canterbury, many natural and modified streams have been subjected to aquatic macrophyte invasion. These exotic plants can have detrimental effects on ecosystem structure and function. This is due to the fact that they may restrict water flow and can alter habitat characteristics (Rabeni et al. 1997). As New Zealand has no native herbivorous fishes, invasive macrophyte growth is mostly controlled either by the use of herbicides or by manual removal. Both of these methods are intrusive and can have long term implications for many organisms within the system. If kekewai show a dietary preference for vigorous exotic macrophyte species, they could potentially play a key role in invasive macrophyte control.

For this study I conducted three experiments. The first was a series of palatability experiments which assessed the food consumption of three types of macrophytes, four types of detritus and two invertebrates. Palatability is defined by the Collins and Oxford dictionaries as “pleasant to taste” whereas the Webster’s New World College dictionary also defines palatability as “pleasant and acceptable to the taste; fit to be eaten or drunk.” It is this definition that is applied to the palatability experiments in this study. The aims of the feeding experiments were to determine what kekewai would consume, and the effects of body size on invertebrate consumption and food preference.

Aims and hypotheses

For this study I conducted three experiments. Firstly, I wished to know how palatable different food items were to kekewai. This experiment assessed the palatability of three types of macrophyte, two types of invertebrate prey and four types of detritus. Secondly, I wanted to determine the effects of body size on the number of prey kekewai would consume. I assessed kekewai size (OCL) and total numbers of prey consumed as well as body weight ratio rate of consumption. Thirdly, I wanted to determine if kekewai would show preference between two food items presented. These choices presented to kekewai were from within the same food groups, that is, a choice between two types of macrophytes, or two prey invertebrates or two types of detritus.

Experiment 1: I expect that kekewai are more likely to consume more plants with soft tissues than invertebrates and detritus. The null hypothesis is that there will be no difference in consumption between foods presented.

Experiment 2: I predict that smaller kekewai will consume more prey in relation to their body size. The null hypothesis is that there will be no difference in invertebrate consumption between larger and smaller individuals.

Experiment 3: This experiment will investigate preferences for foods that were found to be palatable in Experiment 1. The null hypothesis is that there will be no indication of preference within each treatment.

4.2 Methods

Kekewai used in the experiments

Kekewai used in these experiments were gathered from wild populations over periods of 2–12 days with permission from Ngai Tahu, Ngāi Tūāhuriri and in accordance with animal ethics approval 2013/38R. They were collected from the Northbrook site only after all field experiments had been concluded. Some were collected on the last day of trapping trials using the electric fishing method, whilst others were collected using a combination of gee-minnow traps and taukoura. In total there were 117 individuals; 64 males, 50 females and 3 unsexed juveniles. Males ranged in size for orbit carapace length (OCL) from 18 mm (1.343 g), to 48 mm (21.95 – 22.1 g) and females from 14 mm (1.595 g) to 42 mm (18.799gms). However the heaviest recorded male was 46 mm (25.961 g) and the lightest recorded female was 17 mm

(1.35 g). The smallest overall kekewai was 14 mm (0.804 g) but the sex was not recorded. Details of each kekewai and the treatment they were assigned for the first experiment type is shown in Table 4.1.

Kekewai were housed in university aquarium holding tanks which were filled with cycled well water. They were then acclimatised to a temperature of 15°C and 12 h light/dark cycles. Captured kekewai were fed carrot and fish food pellets until enough individuals were collected to conduct an experiment. At the conclusion of an experiment they were returned to the wild, individuals were only used once.

Upon capturing sufficient kekewai for an experiment, the orbit carapace length (OCL) was measured to the nearest millimetre using a fish measuring board and placed into size categories. This method was preferred over the technique used by Kusabs and Quinn (2009) due to the aggressive nature of the specimens and to reduce handling and causing unnecessary stress. Similar to the technique used in Ahvenharju and Ruohonen (2005), absorbent paper towels were used to dry kekewai and remove excess water trapped between the appendages and branchiostegites. However, the majority of water was removed by tail flicking and anti-predator behaviour of the specimens. Individuals were then then weighed to the nearest 0.001g, then they were contained in individual plastic jars that measured 120 mm in length and 90 mm in diameter within the holding tanks. These jars had approximately 126 holes, 5 mm in diameter around the girth which allowed water to flow through. All specimens were then given a slice of carrot for 48 h, after this time the remaining carrot was removed and the kekewai were fasted for approximately 12 h prior to commencement of experiment. This procedure was repeated for all experiments.

Allocation of individuals to each condition was achieved by using stratified random selection. This was to ensure that all conditions had a range of size classes and that each condition would contain both male and female individuals. At the completion of each experiment, kekewai were removed and placed into holding containers before being transported and released back into their natural environment.

Materials and equipment

Experiments were conducted in a temperature controlled room at 15° C with 12 h light dark cycles. A temperature logger placed in a two litre container filled with well water was used to record any fluctuations. Monitoring of experiments was carried out twice over a

24 h period. An Infra-red lighting system was used for monitoring during the dark cycle periods. There were five replicates of each treatment for the palatability experiment. There were five replicates of each treatment for macrophyte preference and invertebrate preference. Due to availability of crayfish there were only four replicates of each detritus treatment for the preference experiment. For body size effects, there were 15 replicates in the mayfly experiment and 20 replicates in the snail treatment.

A single crayfish was placed into a two litre container with PVC pipe as refugia (Figure 4.1). Treatments, which consisted of water and food type were acclimatised in the temperature control room for approximately 12 h prior to kekewai addition and experiment commencement. Each experiment ran for 72 h. The water within the individual containers was oxygenated using a slow flow pump and diffused through an air stone for approximately five minutes on two occasions during the 72 h experiment time. The first was after 24 h and the second was after 48 h. Experimental conditions are shown in Figure 4.1.

Figure 4.1 Experiment set up used in all experiments. Two litre (170 mm x 170 mm x 85 mm) plastic containers were marked 30 mm from the top to allow for 55 mm water depth during experiment. Container lids were measured and marked 25 mm from inside edge along all four sides. Four holes were drilled in the corners where the lines met and then using a craft knife, lines were cut between all the holes. The middle was then pushed out and was replaced with mesh. Five of the lids had 1 x 1 mm mesh with the others having 1 x 2 mm mesh. These were glued onto the lids with hot glue. In each container was placed a refugia constructed from polyvinyl chloride (PVC) pipe which varied in lengths from 60 mm to 100 mm and were approximately 50 mm in diameter.

In total three macrophyte, four detrital and two invertebrate food selections were assessed. The macrophytes used were common macrophytes found in Canterbury streams and included; monkey musk (*Mimulus guttatus*), watercress (*Nasturtium* spp.), and oxygen weed (*Elodea canadensis*). The detrital components were tikouka (*Cordyline australis*), Broadleaf (*Griselinia littoralis*), Willow (*Salix* spp.) and *Pittosporum tenuifolium*. Invertebrates used were mayflies (*Deleatidium* spp.) and snails (*Potamopyrgus antipodarum*). A control treatment was included in which kekewaimwere added with no food type. Macrophyte and detritus controls with no kekewai were also used to control for effects of experimental conditions.

All macrophytes were sourced from streams that kekewai were collected from. Detritus was selected from plants that are commonly found among stream riparian foliage, however not all of these were present in the environment where kekewai were captured. Mayflies and snails were both present at Northbrook, Rangiora, however mayflies and snails used in the experiments were collected from other streams.

Experiment 1: Assessing palatability of individual food types

For the first experiment, macrophytes were harvested and placed into plastic bags along with some of the stream water to prevent drying in transit for preparation in the laboratory. Wet weights of macrophytes were measured 12 h prior to the start of the feeding trials. On arrival at the laboratory, macrophytes were removed from the plastic bags and placed on top of absorbent paper towels, another towel was placed on top and they were pressed dry. They were quickly measured to 5 g wet weights then immediately placed into the waiting experimental containers which had been pre filled with well water and the macrophytes were weighted down with pegs to prevent them from floating on the surface of the water.

The detritus components were measured to 2 g dry weights they were then placed into containers filled with water and left to condition for five days prior to commencement of the experiment. 12 h prior to the start of the experiment, they were removed from water and placed onto a paper towel to absorb excess water then they were immediately placed into two litre containers that had been filled with well water. For both macrophytes and detritus, whole leaves and stems of varying sizes were used to make up starting weights as opposed to leaf fragments.

Five replicates of each macrophyte wet weight and five of each preconditioned detritus weights were used as controls for comparison analysis against treatment conditions. These were subjected to the same procedures and environmental conditions as the experiment treatments. This was to control for any effects that might be attributed to environmental conditions. At the end of the 72 h experiment, remaining detritus and macrophytes along with the controls were collected from each container and placed in individual aluminium foil pockets, they were then oven dried at 60° C for three days. They were then weighed and the mean of the controls was used as the comparison against the mean of the treatments.

For the invertebrate component of the feeding trials, 50 mayflies or 50 snails were placed into 2 litre containers prefilled with well water. This was done immediately prior to experiment commencement. Refugia consisted of a PVC pipe in each container which was used by both kekewai and prey. The experiment ran for 72 h with observations being made at approximately 24 h intervals. Size (OCL), wet weights and sex of kekewai were recorded 24 h prior to commencement of experiment. These along with the treatment they were allocated are shown in Table 4.1 (Appendix B).

Experiment 2: The effects of body size on rate of consumption

To examine the effects of body size on consumption I looked at how many invertebrates would be consumed over a 72 h period. This experiment was run under the same conditions as the palatability feeding trials with the difference being that the kekewai were offered 70 invertebrates at the commencement of the experiment. There were three size classes for the mayfly treatment which ranged from 10 – 19, 20 – 29, 30 – 39 mm and four size classes for the snail treatment which ranged from 10 – 19, 20 – 29, 30 – 39, 40 – 49 mm with approximately five replicates of each size class; these are shown in Table 4.2 (Appendix C). At the conclusion of the experiment any remaining invertebrates were removed and recorded.

Experiment 3: Preference

This experiment was a within groups design and was conducted in a similar manner to the palatability experiments. There were five replicates of each treatment for macrophytes and invertebrates and four replicates of each treatment for detritus. Macrophytes and detritus were prepared as has been described in the previous palatability trials; however kekewai were offered a choice between two food types. In this experiment kekewai were given either 2.5 g

wet weight of each food type for macrophytes or 1 g dry weight of each food type for detritus, the invertebrate choice was 25 each of snails and mayflies.

Analysis

For Experiment 1, assessing palatability, data from macrophyte and detritus treatments were averaged for means comparison against mean control data. Analysis of variance (ANOVA) with Tukeys post hoc was then performed. Invertebrate data were analysed by subtracting remaining invertebrates from initial starting amount to determine the amount consumed. The mean of consumed invertebrates were then analysed using ANOVA. Linear regression was used to assess body size effects on consumption of invertebrates for experiment two. For the third experiment looking at preference, statistical analysis was performed using ANOVA. ANOVA and regression analysis were performed using "R" software, version 3.2.4 in conjunction with Rstudio.

4.3 Results

Experiment 1 Palatability of individual food types

Macrophytes

In the first 24 h shredding occurred in the monkey musk and watercress treatments while most of the oxygen weed remained untouched. After 48 h smaller leaves on the oxygen weed had been removed from the stems and there was some leaf fragmentation. At the end of the experiment most of the stems of the oxygen weed remained intact however there was a lot of leaf debris. The watercress maintained the most whole leaves and monkey musk appeared to be the most fragmented. The majority of leaf fragmentation and debris tended to float on the surface rather than collect at the bottom of the containers.

Kekewai consumed significantly more oxygen weed (0.040 ±S.E 0.006 g) per day (p/d) than watercress (0.019 ±S.E 0.004 g) p/d and monkey musk (0.007 ± S.E 0.001 g) p/d ($F_{2,12}$=13.62, P< 0.01). Amount consumed is shown as dry weight (Figure 4.2). Although they appeared to be different, Tukeys post hoc showed that differences between monkey musk and watercress were not significant (P = 0.18). Macrophyte consumption was not significantly different between males and females ($F_{1,13}$ = 0.48 , P = 0.49). Table 4.3 (Appendix D). shows individual kekewai total consumption for 72 h and mean daily consumption for all treatments. Kekewai consumed an average of 0.24 % (range 0.14 – 0.31

%) of their bodyweight for watercress and an average of 0.54 % (range 0.17 – 1.26 %) of bodyweight for oxygen weed per day.

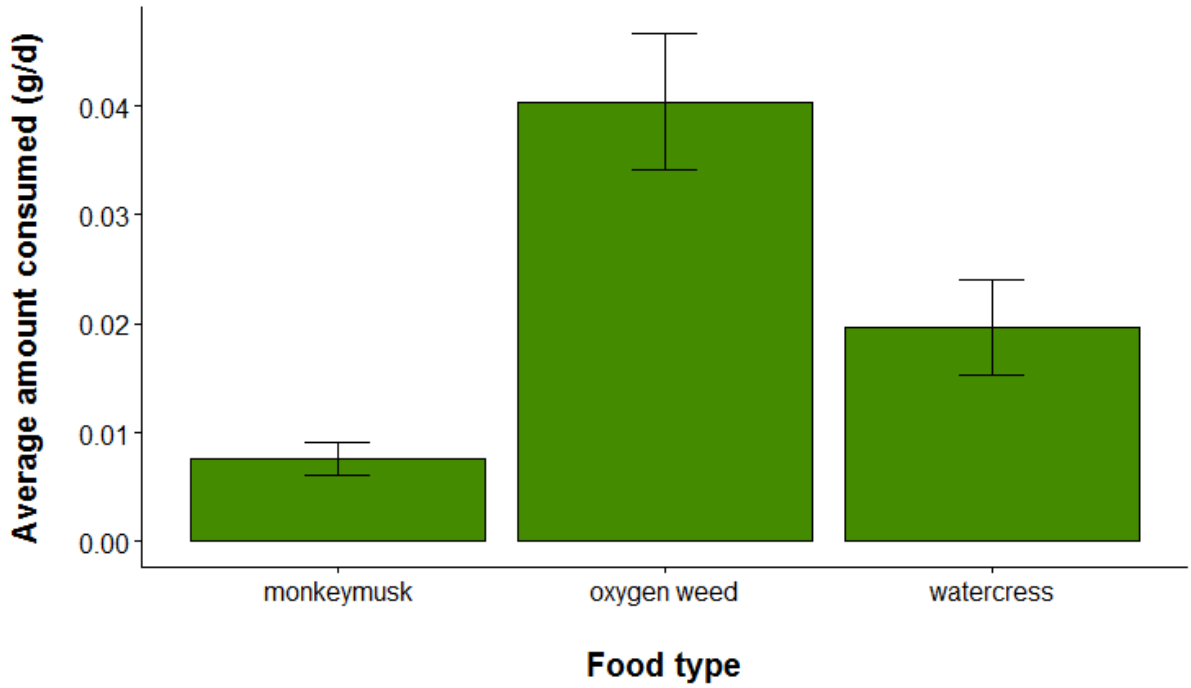

Figure 4.2 Mean (±S.E) consumption (g/dw) of macrophytes eaten per day in palatability experiments

Detritus

Shredding occurred in all *Pittosporum* treatments within the first 24 h. There was little fragmentation in both willow and broadleaf treatments and the tikouka treatments remained untouched. Most of the tikouka treatments remained unchanged for the next 24 h period. There did appear to be some scraping on a couple of leaves, however there was no debris. Detritus processing remained constant for all *Pittosporum* treatments and shredding activity increased in both willow and broadleaf treatments. At the end of 72 h, all of the willow treatments showed various degrees of leaf shredding, however there were still leaves that remained intact. Several leaves in the broadleaf treatments were well shredded with some leaves remaining whole. Two of the tikouka treatments remained untouched. The *Pittosporum* treatments were the most disturbed with the majority of leaves showing signs of

shredding. Mean daily consumption and total amount consumed over 72 h per individual kekewai are shown in Table 4.4 (Appendix E).

Differences for mean daily consumption of detritus treatments between broadleaf (0.045 ±S.E 0.006 g), *Pittosporum* (0.061 ±S.E 0.011 g), tikouka (0.007 ±S.E 0.006 g) and willow (0.025 ±S.E 0.019 g) were significant ($F_{3,16}$=3.05, P=0.05). Tukeys post hoc showed that kekewai consumed significantly more *Pittosporum* than tikouka (P= 0.04), there were no significant differences between the remaining treatments (Figure 4.3). There were no significant differences between sex for detritus consumption ($F_{1,17}$ = 0.21, P= 0.06). Kekewai consumed on average 0.79 % (0.21 – 2.36 %) for broadleaf, 1.01 % (range 0.30 – 2.35 %) for *Pittosporum* and 0.31 % (range 0 – 0.95 %) for tikouka of bodyweight per day.

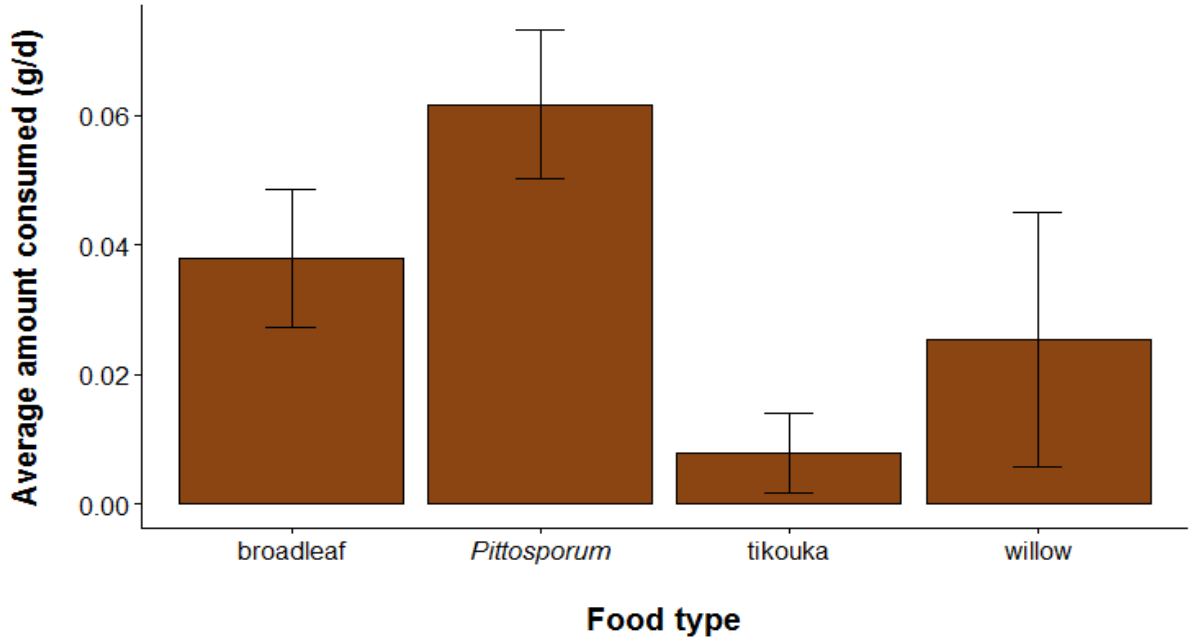

Figure 4.3 Mean (±S.E) consumption (g/dw) of detritus eaten per day in palatability experiments

Invertebrates

For the invertebrate treatments, more than a third of the mayflies were consumed in the first 24 h in four of the five replicates. In the second 24 h period, all prey had been consumed in one of the replicates. At the end of 72 h the majority of mayflies had been consumed in all but one replicate. For the snail treatments, approximately half of the prey were consumed within the first 24 h. For the subsequent 24 h period all snails were consumed

in two replicates. At the end of 72 h, only one replicate had one prey remaining. Table 4.5 (Appendix F) shows total amount consumed over 72 h and mean daily consumption.

Mean daily consumption was 13.733 ±S.E 1.723 for mayflies and 16.600 ±S.E 0.066 for snails (Figure 4.4), however results show no significant differences for invertebrate palatability between mayflies and snails ($F_{1,8}$=2.76, P=0.13). Difference between males and females was non-significant ($F_{1,8}$=0.117, P=0.741) for invertebrate consumption. There were no differences in kekewai size classes between mayfly treatments and snail treatments (F_1,8=0.331, P= 0.581).

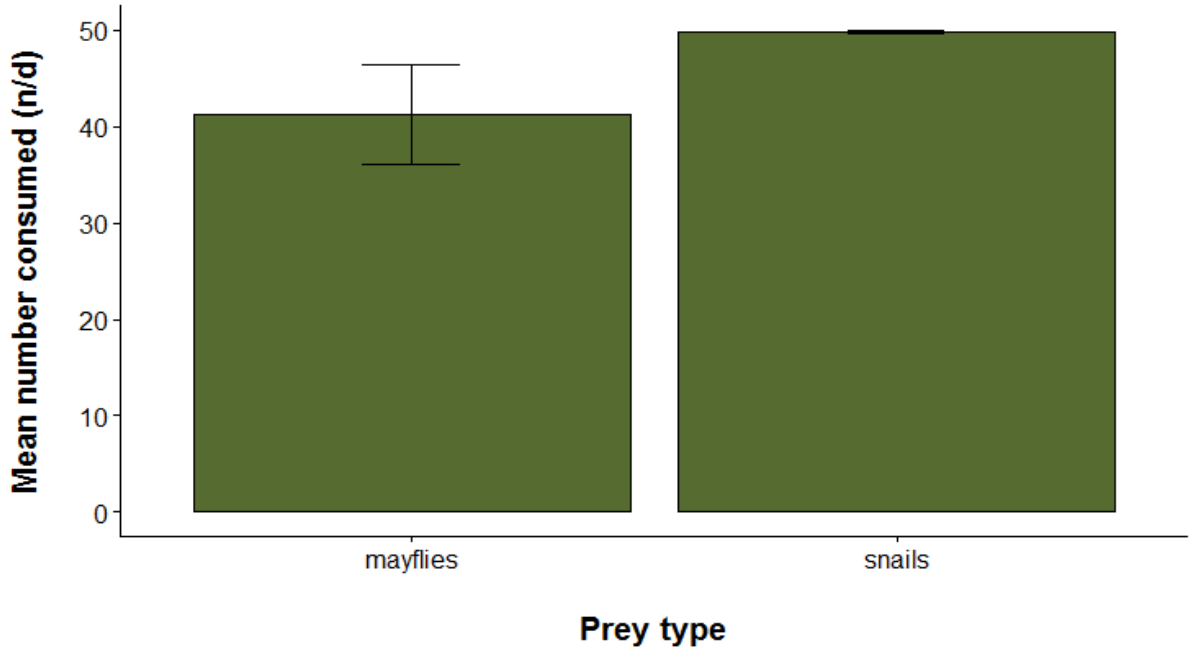

Figure 4.4 Mean (±S.E) number of invertebrates eaten per day in the palatability experiments

Experiment 2: Body size effects on rate of consumption

There were three size classes of kekewai in the mayfly experiment and four size classes in the snail treatment (Table 4.6 Appendix G). Treatments showed varying degrees of predation with the exception of one treatment which was not included in statistical analysis due to kekewai mortality.

Mayflies

After the first 24 h of the mayfly treatments, there was no noticeable difference in prey consumption across the kekewai size classes. In the next 24 h period, larger kekewai had consumed noticeably more prey than smaller kekewai. Within this time frame, one kekewai mortality was recorded. At the end of the 72 h experiment, there was a distinctive difference in prey consumption between the size classes.

In the mayfly consumption trial the regression describing the relationship between kekewai weight and amount consumed was positive and significant (r^2= 0.61, P <0.01) (Figure 4.5). The slopes of the relationship were similar for kekewai OCL and mayfly consumption (r^2= 0.57, P < 0.001).

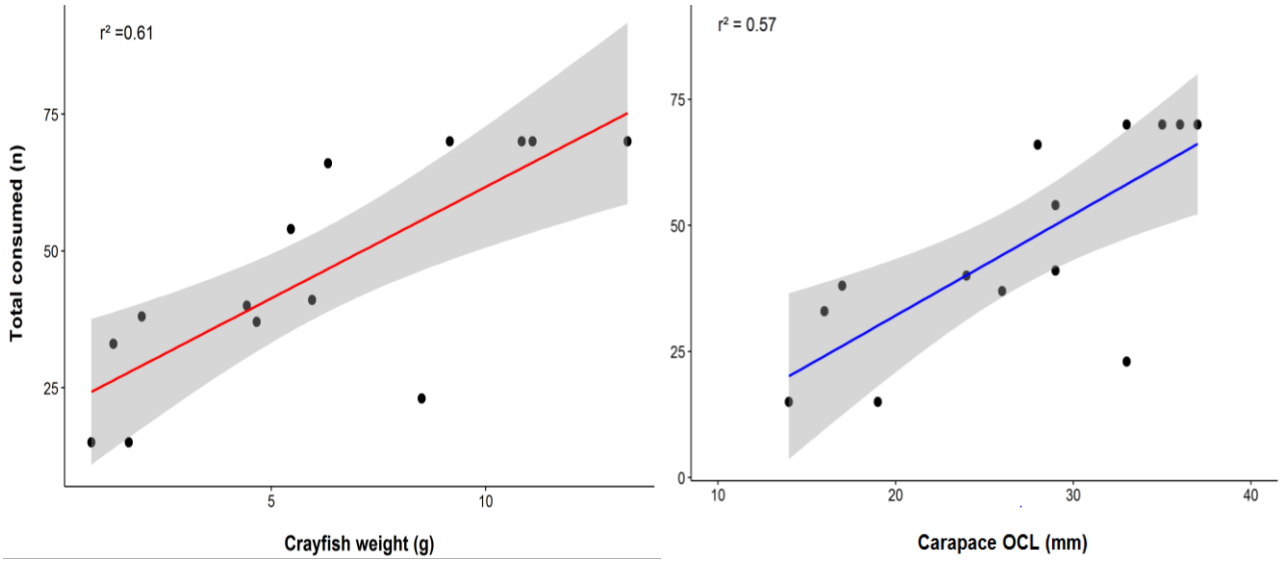

Figure 4.5 Showing relationship between number of mayflies consumed and kekewai weight (red) and carapace length (blue). Shaded areas show 95% confidence intervals

Snails

In the snail treatment most of the prey consumed was within the first 24 h. After the next 24 h, prey was almost completely consumed in half of the snail treatments. In the last 24 h increment prey consumption had ceased in some of the treatments even though there were still prey available.

Regression analysis showed a weak relationship between kekewai OCL and amount of snails consumed (r^2= 0.28, P < 0.001). This relationship was even weaker between kekewai weight and amount of snails consumed (r^2=0.14, P < 0.001) (Figure 4.6). Difference

between weight and OCL for the snail trial was surprising as regression shows that there is a strong positive relationship between kekewai OCL and weight (r^2 = 0.91, P <0.001, n = 96).

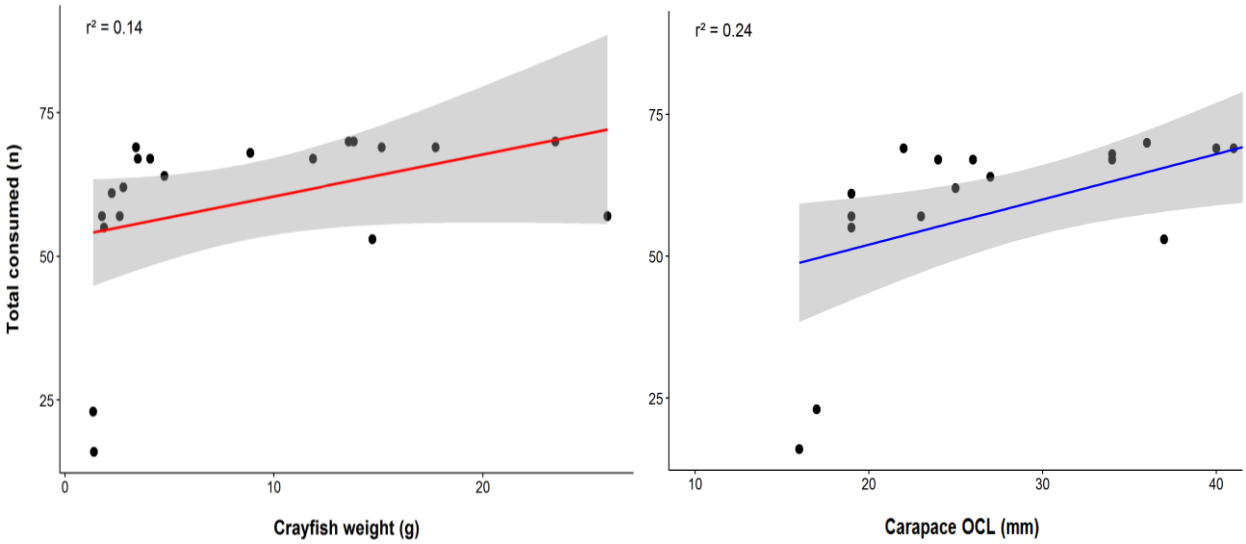

Figure 4.6 Showing relationship between number of snails consumed and crayfish weight (red) and carapace length (blue). Shaded areas represent 95% confidence intervals

Experiment three: Preference

Macrophytes

There was very little shredding for either food choice in the first 24 h of the macrophyte treatments. In the second 24 h time period food choice and leaf fragmentation appeared to be random with no replicates showing any similarities. At the conclusion of the experiment there was a lot of fragmentation and leaf debris, however kekewai selection of food type appeared to be indiscriminate and there were no clear patterns or indications for preferences (Table 4.7. Appendix H)

For within groups analysis of macrophyte treatments, mean daily consumption of watercress (0.008 ±S.E 0.001 g) and monkey musk (0.009 ±S.E0.002 g) was not significantly different for preference ($F_{1,7}$=0.133, P=0.726). Preference was not significantly different ($F_{1,7}$=1.876, P=0.213) for mean daily consumption of monkey musk (0.007 ±S.E 0.0008 g) and oxygen weed (0.004 ±S.E0.002 g). There were no significant differences ($F_{1,7}$=0.004, P=0.954) for mean daily consumption between watercress (0.011 ±S.E 0.001 g) and oxygen weed (0.011 ±S.E 0.005 g). Amounts consumed are shown in dry weights (Figure 4.7)

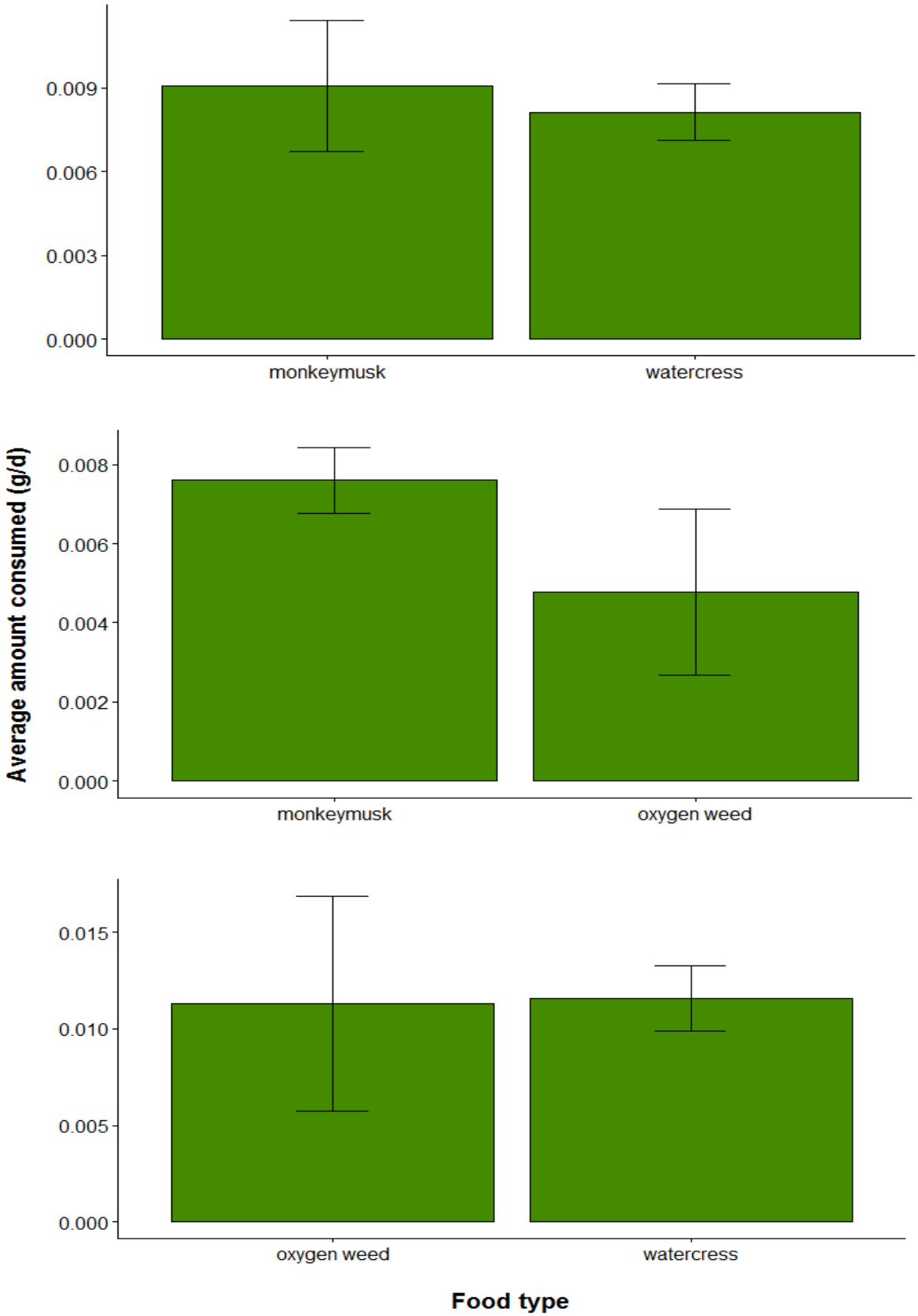

Figure 4.7 Mean (±S.E) daily consumption for grams (g/dw) of macrophytes eaten in preference trials.

Invertebrates

In the invertebrate preference experiments most of the prey consumed was eaten within the first 24 h. Prey choice was random and there was no indication of favouritism for prey items across invertebrate treatments (Table 4.7 Appendix H). Analysis of invertebrates treatments showed no significant differences for preference ($F_{1,7}$=1.925, P=0.208) between mean daily consumption of mayflies (7.8 ±S.E0.454 n) and snails (6.333 ±S.E 0.900 n).

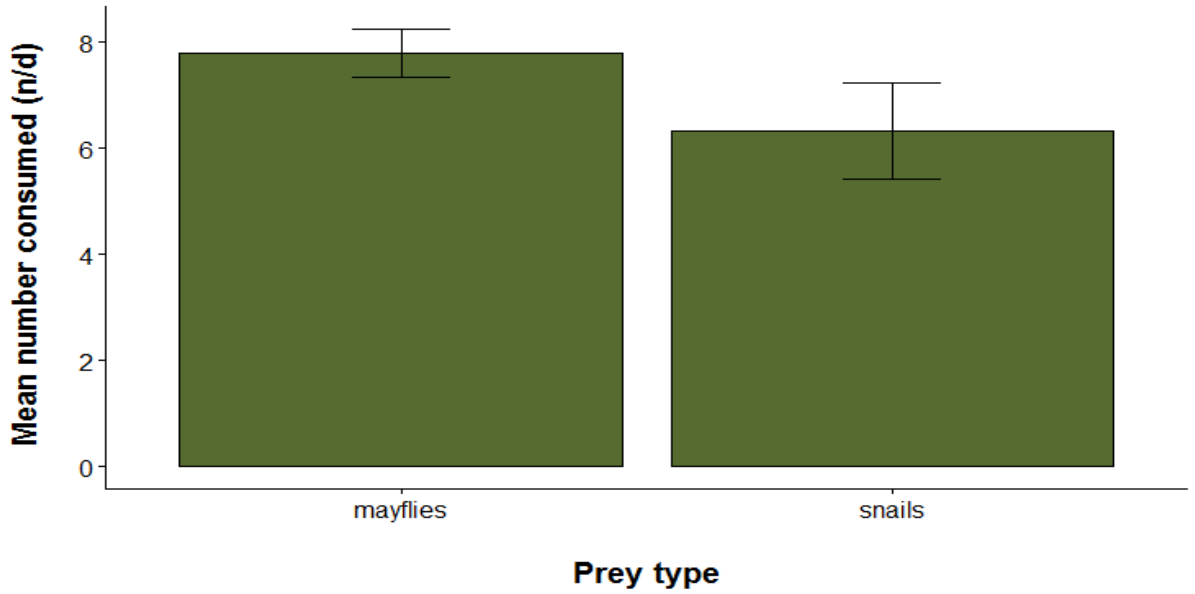

Figure 4.8 Mean (±S.E) daily consumption for numbers of invertebrate prey per day eaten in preference trials

Detritus

After the first 24 h, broadleaf appeared untouched, however willow and *Pittosporum* were well shredded in all treatments. There was very little shredding of broadleaf in all food choice treatments in the following 24 h and *Pittosporum* appeared unchanged in most of the treatments. At the conclusion of the experiment, willow was well shredded across all food choice treatments, shredding of broadleaf had increased, but fragmentation was random across all treatments. During the course of the experiment, the amount of shredding, leaf fragmentation and debris indicated preference for willow over other options presented. Total amount consumed and meandaily consumption are shown in Table 4.8 (Appendix I).

For preference, there were no significant differences ($F_{1,5}$ 0.001 P= 0.971) for mean daily consumption between willow (0.016 ±S.E 0.008 g) and *Pittosporum* (0.017 ±S.E 0.002 g). Differences for mean daily consumption between broadleaf (0.020 ±S.E 0.005 g) and willow (0.013 ±S.E 0.0007 g) were also non-significant ($F_{1,5}$= 1.432, P=0.286). Preference

between mean daily consumption of *Pittosporum* (0.0122 ±S.E 0.006 g) and broadleaf (0.0133 ±S.E 0.007 g) was not significant ($F_{1,5}$=0.009, P=0.93).

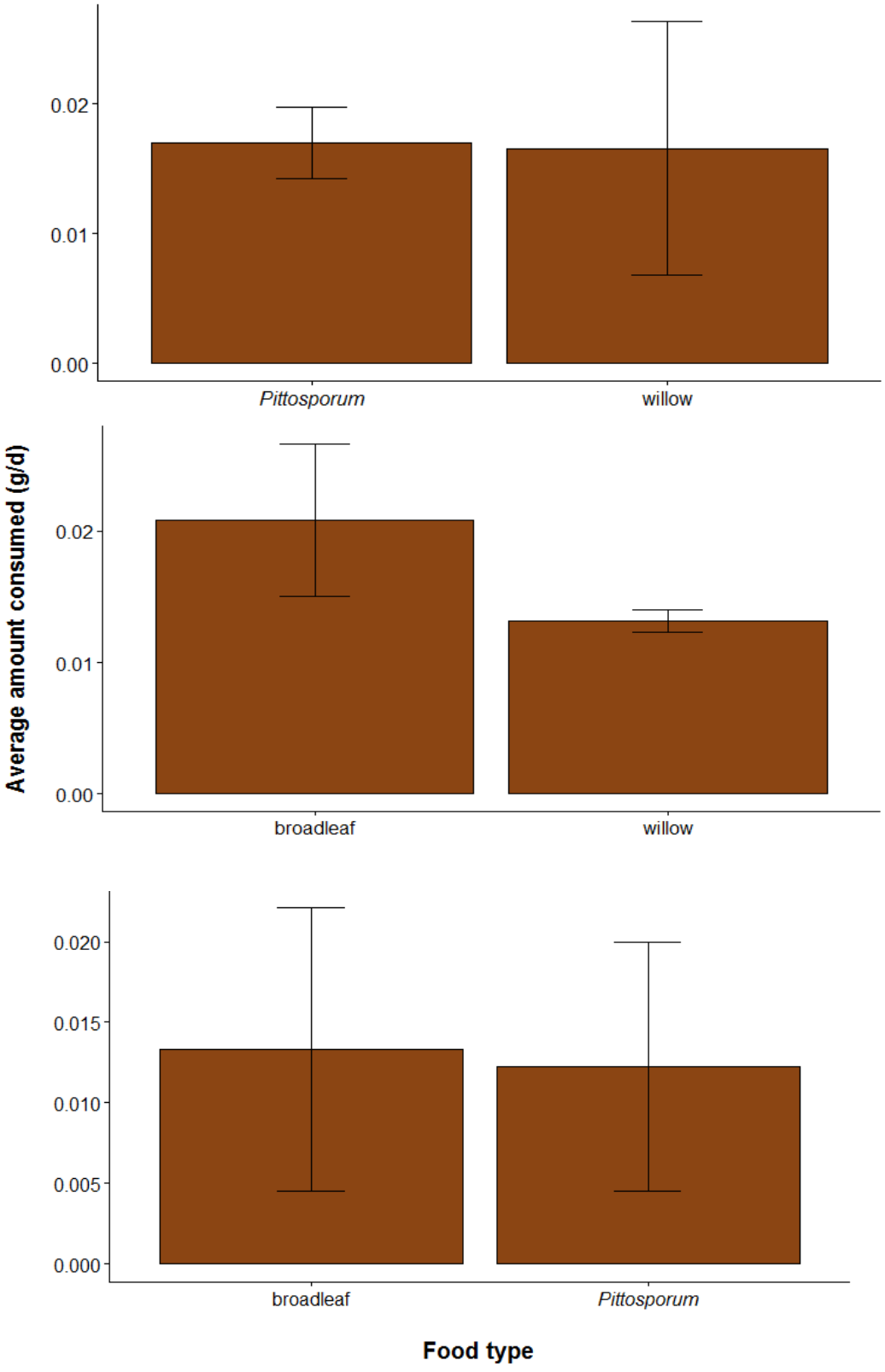

Figure 4.9 Mean (±S.E) daily consumption for grams (g/dw) of detritus eaten in preference trials.

4. 4. Discussion

Kekewai consumed most of the food types offered which supports other claims that crayfish are opportunistic omnivores (Price and Welch 2009, Hoyer et al. 2011, Vehanen et al. 2013). Consumption rates did not appear to be influenced by kekewai size for macrophyte or detrirus treatments in both palatability and preference experiments.

Although kekewai consumed each type of macrophyte presented in the first experiment, they did not consume 1.3 – 1.4% of bodyweight per day as described in Loya-Javellana et al. (1995). This may in part be due to the differences of the food crayfish were presented. In Loya-Javellana et al.(1995), crayfish were fed on pellets, these prepared food substances might be easier to handle and process than natural vegetation. Macrophytes are also more likely to have larger water content than that of pellet foods therefore it is logical to assume that satiation could occur with less actual vegetative material.

Kekewai found oxygen weed the most appealing macrophyte food type, with some animals falling just short of the daily bodyweight percentage reported in Loya-Javellana et al. (1995). This was to be expected as crayfish have been known to prefer the more delicate plant structures than that of coarse fibrous vegetation (Cronin et al. 2002). However, when kekewai were presented with a choice between macrophytes, the mean daily consumption of oxygen weed was less than that of watercress and monkey musk. Although the differences were not significant, they may be a reflection of the opportunistic nature of kekewai and could be indicative of kekewai grazing on what is closest or easily accessible.

Research conducted by Momot (1967) found that the West Lost Lake crayfish in Otsego Co., Michigan were primarily herbivores. This supports other claims that for some crayfish, plants can account for more than 75 % of the diet (Geiger et al. 2005). Macrophyte grazing crayfish show a preference for delicate fresh plants that have filamentous or diaphanously branched structures (Cronin et al. 2002). Therefore, it would be reasonable to assume that Kekewai would find oxygen weed to be the most palatable followed by watercress, with coarse fibrous monkey musk being the least appealing.

Although there were no significant differences for consumption between detritus treatments in the palatability experiments, kekewai did consume considerably more detrital material than fresh vegetation. Dicotyledon plant detritus were consumed at a higher rate than monocotyledon detritus, and native dicotyledons, *Pittosporum* and broad leaf were consumed

at a higher rate than the exotic willow. All detritus treatments were highly variable both in palatability and preference experiments. Male crayfish process detritus at a faster rate than females (Usio and Townsend 2002), however in the palatability experiment there were no significant differences between males and females for detritus consumption.

In total, for palatability, 206 out of 250 mayflies were consumed over 72 h, whereas 249 out of 250 snails were consumed. As there were no significant differences for kekewai size between the invertebrate treatments, this was not expected to have any effect on rates of predation. Whilst more snails were preyed on than mayflies in the palatability experiments, the differences were not significant. Snails and mayflies are among the most common invertebrates consumed by kekewai (Parkyn et al. 2001, Hollows et al. 2002) and numbers of prey consumed are determined by availability (Parkyn et al. 2001). This is reflected in the results of the preference experiments where prey selection was random with both mayflies and snails being indiscriminately preyed upon.

Moshiri and Goldman (1969) cited in Momot et al (1978), conducted experiments with the crayfish *Pacifastacus leniusculus*, to investigate assimilation efficiencies of plant and animal material. They found that although assimilation of plant material was lower than that of animal matter, the crayfish compensated by consuming a greater proportion of plant material than they did of animal matter. In the present study examining palatability, it appeared that crayfish that were offered invertebrates consumed more than crayfish that were offered vegetation or detritus. This assumption is based mainly on the observation that the majority of invertebrate prey, in particular the snails, were consumed within the first 48 h of the experiment. However, it must be noted that invertebrate biomass was not weighed and therefore comparisons of biomass consumption of invertebrates to that of macrophytes and detritus cannot be accurately determined.

Size selection of kekewai for both palatability and preference experiments were evenly distributed. These helped to ensure that results were representative of treatment conditions and were less likely to be influenced by size effects. Larger crayfish are more inclined to process detritus and smaller individuals tend to be more voracious predators (Parkyn et al. 2001), therefore it was imperative that all experiments had equal representation for range of size classes.

For body size effects on consumption I observed that larger kekewai consumed considerably more mayflies than smaller kekewai. Although for foregut capacity, it would appear more logical to expect larger crayfish to consume more than smaller crayfish, this is not what is expected for predation. As smaller crayfish have been reported to consume more invertebrates than larger crayfish (Parkyn et al. 2001), I would have expected to see less effects of size on predation. This is reflected more in the snail treatment where numbers of snails preyed on by smaller kekewai was similar to that of their larger counterparts. However, this was also unexpected as invertebrates, and in particular *Deleatidium* and *Aoteapsyche,* were the most dominant prey items found in kekewai gut analyses in the study conducted by (Whitmore et al. 2000). Therefore, I would have expected smaller kekewai to consume a higher number of mayflies than snails. A possible reason why more snails that mayflies were consumed could be that mayflies have greater mobility and were therefore able to evade capture, whereas snails, which are slower moving may have proven to be easier prey. The results of these experiments were interesting as they clearly show that foregut capacity does not necessarily dictate the amount of prey a crayfish can consume but rather the amount of prey that a crayfish chooses to consume.

Preference experiments were within groups designs, that is, food choices belonged to the same food category, macrophytes, detritus or invertebrates. This within groups design showed no significant differences in any of the treatments. If this experiment was repeated using a between groups design by offering kekewai a choice of food type from two different categories, we might expect to see definite choices between food types offered. All experiments were conducted on individually housed kekewai along with treatments. There were no experiments that had multiple kekewai within treatments, therefore competitive interactions could not be observed. If kekewai had to compete for resources this might have influenced consumption rates and perhaps even choice in preference experiments.

Although ideally I would have preferred to compare pre-experiment wet weight against post experiment wet weights for macrophytes, this proved to be problematic. Post experiment weighing meant that the towel drying of smaller particles was difficult as they had a tendency to disintegrate, and without towel drying they could hold a substantial amount of water. Also the weighing process needed to be completed quickly to ensure that the amount of evaporation was minimised. These problems were quickly identified in the preliminary experiments.

I used five replicates for each of the palatability experiments as well as for the macrophytes and invertebrates preference treatments; however the detritus preference treatments had four replicates, due to availability of crayfish. Greater numbers of replicates could have provided more robust results across all treatments, unfortunately I was limited by the number of kekewai I was able to capture. I did consider using farmed crayfish instead of feral populations to increase my sample size, however the foraging behaviour of farmed individuals may not be indicative of the behaviour of feral kekewai.

Other factors that may have influenced my results were life stage of different individual crayfish. Similar to other crustaceans, freshwater crayfish growth is limited by the capacity of the exoskeleton, therefore in order to increase in size, crayfish must first undergo moult (Hammond et al. 2006). Crayfish that are ready to moult are less inclined to forage, they decrease activity and feeding ceases (Hammond et al. 2006). In order to defend themselves against predation and to protect against cannibalism, the new exoskeleton needs to harden quickly (Hammond et al. 2006), therefore crayfish are more inclined to forage for sources of calcium, which often means that their first meal after moult is their shed exoskeleton. Although soft shelled individuals were not retained after capture, it can be difficult to determine if crayfish are preparing to moult or when the last moult occurred. This may have influenced some of the foraging behaviours of the kekewai in the experiments.

Although kekewai will consume exotic macrophytes, it does not appear that they would make a substantial contribution to invasive macrophyte control. As the present study did not examine all combinations of food, it is also unknown if kekewai would choose to consume macrophytes over other food groups. Further research is needed to fully understand feeding preferences of kekewai and to determine if this is influenced by life stage or population density.

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Practical applications and future directions

5.1 Introduction

Freshwaters are a source of natural resources and are highly valued in cultural, economic, aesthetic, educational and scientific terms (Dudgeon et al. 2006). Although freshwater makes up only 0.01% of the Earth's water, it supports almost 6% of all described species (Dudgeon et al. 2006). There is much focus and attention on the decline of terrestrial species however, it has been estimated that fresh water fauna are declining at a rate five times higher than that of their terrestrial counterparts and more than three times that of coastal marine mammals (Ricciardi and Rasmussen 1999, Dudgeon et al. 2006). One quarter of all living vertebrate species are comprised of freshwater fishes and as many as 30% of these are threatened (Abell 2002). Threats to some of the other freshwater faunal groups are considered to be even greater (Abell 2002). Much of this decline has been attributed to habitat degradation (Casatti et al. 2006, Didham et al. 2007). Decreasing freshwater fauna abundance has been shown to be affected more by changes to physical habitats than that of effluent pollutants (Casatti et al. 2006), however culmination of these factors can exacerbate effects. Invasive species are also known to contribute to fresh water biodiversity loss (Gurevitch and Padilla 2004).

Freshwater crayfish are among the most at risk species with more than 30% being classified as either highly threatened or at risk of extinction (Taylor et al. 2007, Aquiloni et al. 2010, Richman et al. 2015). This number may in fact be much higher as there are many crayfish species that have yet to be assessed for conservation status (Taylor et al. 1996, Crandall and Buhay 2008). In common with other threatened freshwater fauna, the main drivers of crayfish decline are habitat degradation and invasive species (Wilcove et al. 1998, Didham et al. 2007, Richman et al. 2015). This thesis research investigated aspects of the distribution and biology of the New Zealand crayfish *P. zealandicus* to inform future management decisions. My research identified three main areas of concern. The first is the declining distribution and populations of kekewai in central Canterbury, secondly that many habitats have been degraded and thirdly, effective monitoring programmes and then conservation management need to be established.

In New Zealand, *Paranephrops* spp. are currently listed as not threatened, however, *P. zealandicus* is classified as declining at a rate of 10 – 70% (Grainger et al. 2014). It is unclear as to what timeframe that this decrease is predicted. The difference in conservation status for the two species could possibly be that as *P. planifrons* has a greater geographical range than that of *P. zealandicus*, and therefore is liable to be found in more locations. The current status for *P. zealandicus* in Canterbury is becoming increasingly dire, there have been many changes and modifications to and around most of the water bodies that I surveyed. These modifications include agricultural intensification, suburban development and increasing urban areas. As a result, there are a number of streams that have altered flow regimes, and an increasing number of streams that have poorer water quality. These changes that are affecting habitats could potentially be disastrous for the current kekewai populations.

5.2 Kekewai distribution and populations

In the present study, Kekewai were not detected in many of the water bodies where they use to exist, which suggests that approximately 80% of historic kekewai sites have been lost. Although some of the low detection rates can be attributed to the limitations of the methodology used, it still does warrant further investigation. Historically, many of the streams that I surveyed had abundant populations that were quickly and easily detectable (L. de Groot., A. Blokker pers. comms). The absence of kekewai in some streams and the difficulty in detecting them in others suggests that there has been a decline in populations in central Canterbury water bodies. This decline is most likely a result of significant changes in land use which has altered the current habitats.

Habitat degradation is often the outcome of anthropogenic modifications (Meybeck 2003). Land use change such as from agricultural, commercial and residential development, can have negative effects on local freshwater environments. Loss of habitat components such as gravel and boulder substrates, vegetation and woody debris through dredging and channelisation can have catastrophic consequences for crayfish populations (Taylor et al. 2007). One of the most striking observations I made in many of the water bodies that I investigated was changes in sediment loading. Particularly obvious was the inundation of fine sediments in previously cobbled substrates. This is especially concerning as substrate is considered to be one of the most important factors in determining crayfish abundance (Capelli and Magnuson 1983). Although kekewai are known to be active burrowers, (Whitmore et al. 2000) and are sometimes found in stream bank crevices (L. de Groot, pers

coms 2015), increased sediment inundation could limit potential food resources. A study on inundation conducted by Burdon (2013) on 30 Canterbury streams showed that community composition of benthic invertebrates changed with increased sedimentation. His research found that fine sedimentation coverage of more than 20% decreased habitat availability and therefore had negative effects on presence and abundance of sensitive EPT (Ephemeroptera, Plecoptera and Trichoptera) taxa (Burdon 2013). As invertebrates are an important food source that significantly contributes to growth and development (Parkyn et al. 2001, Hollows et al. 2002), changes in invertebrate community composition are likely to have negative impacts on kekewai.

It has been shown in the current study that kekewai will consume macrophytes, however the consumption rate was very low (Chapter 4). Although macrophytes provide some habitat and refugia for other invertebrates as well as kekewai (Biggs and Malthus 1982), they can also potentially exclude kekewai when macrophytes become prolific. Hessen et al. (2004), investigated the effects of invasive *Elodea canadensis* on crayfish populations in Norway. He found that the rapid growth of this invasive macrophyte far exceeded the crayfish's ability to control it and therefore paradoxically, crayfish were spatially excluded by the potential resource (Hessen et al. 2004). This was because crayfish were unable to move within the dense strands of macrophytes, which in turn limited the area that crayfish could inhabit (Hessen et al. 2004). This could also potentially be the case for kekewai in central Canterbury, where prolific macrophyte growth could possibly limit recruitment and dispersal of current kekewai populations. This could warrant further investigation as the potential effects of prolific macrophyte growth on kekewai movement and dispersion and consequently other native fishes are not fully understood.

5.3 Traditional ecological knowledge

Traditionally, Māori had a natural affinity with, and aspiration for their environment which was shaped by their spiritual beliefs. This in turn was guided by the principles and values of kaitiakitanga (stewardship), mauri (life force), rahui (regulation, restrictions, or temporary closure), tapu (sacred), mana (prestige, power), noa (free from tapu) and wairua (spiritual qualities/dimension) (Harmsworth and Tipa 2006). Māori had a deep understanding of ecosystem connectivity and believe that all aspects of the physical environment were interconnected and interdependent through the domains of departmental gods or Atua (Harmsworth and Tipa 2006).

Increasingly, cultural values are being incorporated into the management of aquatic ecosystems. These values may be qualitative rather than quantitative but they hold great cultural significance. Some scientists are reluctant to accept and incorporate this knowledge which may have been used by previous generations of peoples who have depended upon their environment for subsistence. Indigenous people have intimate knowledge of their harvesting areas which could contribute to improve our scientific knowledge. However, it is also very important that some sites which have special status for Māori remain confidential. People that rely on these resources are very aware of habitat and environmental factors that are important for the species that they harvest. They monitor the species and are able to identify certain factors that scientists may not have the available resources or time to investigate. Sometimes their observations of habitat change, species mutualisms or changes in community composition can enhance our understandings of ecosystem functions. One such observation was the relationship that kekewai have with kakahi (freshwater mussels). In a conversation with a Māori elder, who wishes to remain anonymous, I was told that "If you want to find the kekewai, you need to look for the kakahi. The kekewai help the young of the kakahi to go to new areas, if there are a lot of kakahi, especially young ones, then there will be a lot of kekewai" (Kaumātua, pers.coms 2014). Although this has yet to be investigated scientifically, this potential relationship does warrant some consideration.

As local people are aware of the conditions in the environment that they use, they are potentially the best candidates to implement citizen science. They have a vested interest in the continuing sustainability of the resources and their contributions would be beneficial not only for themselves and the greater community but could also improve scientific knowledge. This in turn allows for more structured and targeted management strategies to be employed.

5.4 Potential management

The first step in deciding the most effective and appropriate management strategies is determining what goals need to be attained (Rounick and Winterbourn 1982). There are many factors to consider, such as land use and water body types and the different combinations of each. Consequently, it would be impossible to design a definitive management strategy that would satisfactorily address all of the issues and could be implemented in all systems. Therefore, rehabilitation efforts will need to be tailored to suit the needs and goals for each land use and water body type.

Monitoring and habitat rehabilitation

Some of the streams investigated in the present study were part of restoration projects. A number of studies that have assessed crayfish habitats in New Zealand have examined stream physico-chemical aspects as well as physical habitat characteristics (Usio and Townsend 2000, Jowett et al. 2008, Kusabs et al. 2015). However, there are few studies that have investigated techniques that could be implemented to restore or enhance crayfish habitats. One such study conducted by Parkyn et al. (2009), used wood to create and enhance habitats for *P.planifrons*. In that study, stable logs were placed across stream channels which increased heterogeneity and habitat complexity. They found that overall, wood influenced crayfish occurrence and there were also increases in crayfish abundance and size (Parkyn et al. 2009). Modification of water bodies in central Canterbury has seen changes that have resulted in homogeneity of habitats. Therefore, introduction of natural materials such as logs could facilitate heterogeneity and greatly improve kekewai habitat. In addition, removing invasive predators such as trout or creating barriers to exclude them from kekewai habitats could also aid in restoring declining populations.

In the present study prolific macrophytes were observed in most of the streams studies. Many of the current techniques for controlling macrophytes can be physically destructive to stream habitat. These include chemical control such as herbicides or mechanical removal using machinery. Unfortunately, using machinery often not only removes vegetation but can also remove substrate. Observations at some of the sites I surveyed found that there was very little macrophyte growth when there was full shading over the stream. An example of this is at the Northbrook site where I conducted trapping trials (Chapter 4). This site had prolific macrophyte growth in a large proportion of the stream where there was very little riparian vegetation. However, for approximately 50 m along the north facing side of the stream was a hawthorn hedge (> 2m height). Along the areas where this hedge completely shaded the stream throughout the whole day no macrophytes were present.

Capture techniques for monitoring

Electric fishing was shown to be the most effective of all fishing methods trialled for kekewai (Chapter 3). Electric fishing showed no bias for sex or size as opposed to other methods assessed in my study. However, electric fishing is limited to shallow waterbodies and is difficult to use in vegetated areas (Alonso 2001, Price and Welch 2009). Passive trapping methods such as gee-minnow and tau-kōura did show bias in my study. Gee-minnow traps were biased towards large individuals and tau-kōura were biased towards juveniles. Due to these biases, individually these methods would not give an accurate representation of population structure. However, if these methods were to be deployed together, they would likely capture a representative sample of population structure. In addition, not only could tau-kōura be a useful tool for monitoring, but could potentially be used as a nursey habitat for juveniles.

Community based management

Monitoring indicators used at larger geographic scales are often not suitable or sufficient for use at a local scale (Boyd and Charles 2006). Management and rehabilitation efforts at the local scales are often limited by funding. Initial costs of rehabilitating degraded environments can be expensive. Citizen science monitoring could be used for some aspects of monitoring provided it was undertaken under the guidance of experts, including Runanga. The cultural values recorded can be used to follow population trends and set environmental standards (Harmsworth and Tipa 2006). This would allow inclusion of cultural and scientific perspectives (Harmsworth 2002).

5.5 Sustainable mahinga kai harvest and commercial prospects

Kekewai fall under the jurisdiction of Ministry of Primary Industries (MPI) and are in the same gathering category as many shellfish species. They are part of the combined bag limit, which is 50 per person per day (Ministry of Primary Industries 2014). This means that an individual could take up to 50 crayfish. From this thesis research such a catch rate would not be sustainable in Canterbury waterways I studied. The limits clearly need to be reviewed in this region and a full evaluation undertaken before new limits could be set.

Many freshwater crayfish species have been successfully harvested overseas from both wild and cultured populations (Taylor et al. 1996). They are an important food source and in the 1990's had proven to be economically lucrative with worldwide estimations of up

to 100,000 metric tonnes being produced commercially each year (Taylor et al. 1996). However, overfishing, pollution and crayfish plague dramatically reduced crayfish production and exports in some areas (Harlioğlu 2004). Although these fisheries are slowly recovering, there is still market potential for this resource (Harlioğlu 2004).

There is some freshwater aquaculture undertaken in South Canterbury and Kaikōura but there is little information about the culture conditions used. Kekewai translocation and/or seeding is another strategy that could be used to help repopulate rehabilitated systems that once had kekewai populations. Feeding studies such as those used in the present study can be used to quantify nutritional requirements for development and growth.

5.6 Future studies

My research identified declining kekewai populations and deficiencies in present kekewai monitoring within central Canterbury. I suggest a standard methodology involving several techniques including tau-kōura. These techniques need to be tested in different localities in a variety of water body types. The results from my study show that kekewai from Canterbury feed on a variety of food types but it is likely that preferences may depend on availability in the habitat or prior feeding history. This aspect needs further investigation.

This research has used traditional Maori knowledge as a basis for scientific investigation. It has contributed to the distribution patterns and capture techniques. Many people have shared their knowledge with me and I am respectful of their contributions. The research has also been a platform for educating others about taonga species. Together, the combination of scientific research and traditional concepts provide a pathway and framework for the future conservation and management for kekewai and other taonga species.

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Appendix A

Table 3.2 Number of males (M), females (F) and juveniles (J) caught by electric fishing methods at sites from all three reaches.

Sampling method Electric fishing				
Reach	**Site**	**M**	**F**	**J**
Northbrook	1	6	5	9
	2	4	1	4
	3	3	1	3
	4	0	0	0
	5	0	1	1
	6	0	0	0
Marsh Road	1	2	0	0
	2	1	1	2
	3	0	0	0
	4	0	0	0
	5	1	0	1
	6	0	0	0
Liffey Springs	1	2	1	0
	2	1	0	4
	3	0	1	1
	4	1	0	1
	5	1	0	0
	6	1	0	1

Appendix B

Table 4.1 Showing kekewai and treatments for palatability experiments. Wet weights (W/W) of kekewai have also been recorded. Weights not recorded are represented by dashes. Kekewai control conditions were kekewai with no food. All experiments were run under the same conditions over three different occasions.

Macrophytes				Invertebrates				Detritus			
OCL (mm)	**W/W (g)**	**Sex**	**Treatment**	**OCL (mm)**	**W/W (g)**	**sex**	**Treatment**	**OCL (mm)**	**W/W (g)**	**Sex**	**Treatment**
44	-	M	monkey musk	31	-	F	mayflies	44	-	M	willow
27	-	F	monkey musk	39	-	F	mayflies	28	-	F	willow
32	-	M	monkey musk	24	-	M	mayflies	29	-	M	willow
35	-	M	monkey musk	21	-	M	mayflies	34	-	M	willow
33	-	M	monkey musk	37	-	M	mayflies	37	-	M	willow
40	14.31	F	watercress	25	3.17	M	snails	25	3.17	M	*Pittosporum*
36	11.09	M	watercress	31	7.834	F	snails	36	12.81	M	*Pittosporum*
29	5.569	F	watercress	34	7.47	M	snails	31	8.06	F	*Pittosporum*
31	7.593	M	watercress	37	13.62	F	snails	34	10.83	M	*Pittosporum*
31	7.246	M	watercress	37	14.31	M	snails	31	7.047	F	*Pittosporum*
48	22.1	M	oxygen weed	34	-	M	control	21	2.202	F	tikouka
31	8.06	F	oxygen weed	36	-	M	control	24	3.337	F	tikouka
28	4.362	M	oxygen weed	27	-	M	control	37	11.79	M	tikouka
39	15.61	M	oxygen weed	28	-	F	control	48	21.95	M	tikouka
29	6.573	F	oxygen weed	45	-	M	control	41	18.518	F	tikouka
								22	2.621	F	broadleaf
								24	3.507	M	broadleaf
								36	10.416	F	broadleaf
								47	22.936	M	broadleaf
								42	18.799	F	broadleaf

Appendix C

Table 4. 2 Carapace length (OCL), wet weight (W/W) and sex of kekewai for experiment 2 body size effects on rate of consumption.

OCL (mm)	W/W (g)	Sex	Treatment	OCL (mm)	W/W (g)	Sex	Treatment
14	0.804	-	mayflies	16	1.382	F	snails
16	1.317	-	mayflies	17	1.35	F	snails
17	1.983	-	mayflies	19	1.769	F	snails
19	1.677	F	mayflies	19	1.864	M	snails
19	1.822	F	mayflies	19	2.241	M	snails
24	4.431	M	mayflies	22	3.396	M	snails
26	4.662	M	mayflies	23	2.624	F	snails
28	6.324	M	mayflies	24	3.479	F	snails
29	5.461	F	mayflies	25	2.792	F	snails
29	5.953	M	mayflies	26	4.076	M	snails
33	8.51	F	mayflies	27	4.758	M	snails
33	9.168	M	mayflies	34	8.871	F	snails
35	10.843	M	mayflies	34	11.867	M	snails
36	13.31	M	mayflies	36	13.573	F	snails
37	11.097	M	mayflies	36	13.819	M	snails
				37	14.711	M	snails
				40	15.154	F	snails
				41	17.735	M	snails
				46	25.961	M	snails
				47	23.469	M	snails

Appendix D

Table 4.3 Results for total amount consumed and mean daily consumption of macrophytes. Carapace length (OCL), wet weight (W/W) and sex of kekewai also recorded**.**

OCL (mm)	W/W (g)	sex	Treatment	Total amount consumed (g)	Mean daily consumption (g)
44	-	M	monkey musk	0.027	0.009
27	-	F	monkey musk	0.023	0.008
32	-	M	monkey musk	0.025	0.008
35	-	M	monkey musk	0.006	0.002
33	-	M	monkey musk	0.034	0.011
40	14.31	F	watercress	0.061	0.020
36	11.09	M	watercress	0.096	0.032
29	5.569	F	watercress	0.015	0.005
31	7.593	M	watercress	0.057	0.019
31	7.246	M	watercress	0.068	0.023
48	22.1	M	oxygen weed	0.138	0.046
31	8.06	F	oxygen weed	0.073	0.024
28	4.362	M	oxygen weed	0.166	0.055
39	15.61	M	oxygen weed	0.080	0.027
29	6.573	F	oxygen weed	0.149	0.050

Appendix E

Table 4.4 Total amount consumed over 72 h and mean daily consumption of detritus treatments. Orbit Carapace Length (OCL), wet weight and sex of individual kekewai as well as assigned treatments are also recorded.

OCL (mm)	W/W (g)	Sex	Treatment	Total amount consumed (g)	Mean daily consumption (g)
21	2.202	F	tikouka	0.063	0.021
24	3.337	F	tikouka	0.052	0.017
37	11.79	M	tikouka	n c	0.000
48	21.95	M	tikouka	n c	0.000
41	18.518	F	tikouka	0.046	0.015
22	2.621	F	broadleaf	0.186	0.062
24	3.507	M	broadleaf	0.064	0.021
36	10.416	F	broadleaf	0.159	0.053
47	22.936	M	broadleaf	0.147	0.049
42	18.799	F	broadleaf	0.148	0.049
44	-	M	willow	0.268	0.089
28	-	F	willow	0.004	0.001
29	-	M	willow	0.064	0.021
34	-	M	willow	n c	0.000
37	-	M	willow	0.127	0.042
25	3.17	M	*Pittosporum*	0.272	0.091
36	12.81	M	*Pittosporum*	0.202	0.067
31	8.06	F	*Pittosporum*	0.171	0.057
34	10.83	M	*Pittosporum*	0.219	0.073
31	7.047	F	*Pittosporum*	0.064	0.021

Appendix F

Table 4.5 Showing Kekewai wet weight (W/W), carapace length (OCL), sex and prey type with total number of prey consumed over 72 h as well as mean daily prey consumption.

OCL (mm)	W/W (g)	Sex	Treatment	Total numbers consumed (n)	Mean daily consumption (n)
31	-	F	mayflies	39	13.000
39	-	F	mayflies	49	16.333
24	-	M	mayflies	46	15.333
21	-	M	mayflies	22	7.333
37	-	M	mayflies	50	16.667
25	3.17	M	snails	50	16.667
31	7.83	F	snails	50	16.667
34	7.47	M	snails	50	16.667
37	13.62	F	snails	49	16.333
37	14.31	M	snails	50	16.667

Appendix G

Table 4.6 Kekewai carapace size (OCL), wet weight (W/W) and sex with total amount and mean daily prey consumption

OCL (mm)	W/W (g)	Sex	Treatment	Total amount consumed (n)	Mean daily consumption (n)
14	0.804	-	mayflies	15	5.0
16	1.317	-	mayflies	33	11.0
17	1.983	-	mayflies	38	12.7
19	1.677	F	mayflies	15	5.0
19	1.822	F	mayflies	N/A	N/A
24	4.431	M	mayflies	40	13.3
26	4.662	M	mayflies	37	12.3
28	6.324	M	mayflies	66	22.0
29	5.461	F	mayflies	54	18.0
29	5.953	M	mayflies	41	13.7
33	8.51	F	mayflies	23	7.7
33	9.168	M	mayflies	70	23.3
35	10.843	M	mayflies	70	23.3
36	13.31	M	mayflies	70	23.3
37	11.097	M	mayflies	70	23.3
16	1.382	F	snails	16	5.3
17	1.35	F	snails	23	7.7
19	1.769	F	snails	57	19.0
19	1.864	M	snails	55	18.3
19	2.241	M	snails	61	20.3
22	3.396	M	snails	69	23.0
23	2.624	F	snails	57	19.0
24	3.479	F	snails	67	22.3
25	2.792	F	snails	62	20.7
26	4.076	M	snails	67	22.3
27	4.758	M	snails	64	21.3
34	8.871	F	snails	68	22.7
34	11.867	M	snails	67	22.3
36	13.573	F	snails	70	23.3
36	13.819	M	snails	70	23.3
37	14.711	M	snails	53	17.7
40	15.154	F	snails	69	23.0
41	17.735	M	snails	69	23.0
46	25.961	M	snails	57	19.0
47	23.469	M	snails	70	23.3

Appendix H

Table 4.7 Results of preference experiments for macrophyte dry weight (g) and invertebrates (n) with total amount consumed over 72 h and mean daily consumption. Kekewai carapace size (OCL), wet weight (W/W) and sex is also recorded

OCL (mm)	W/W (g)	Sex	Food Choice 1	Total consumed (g/ n)	Mean daily consumption (g/ n)	Food Choice 2	Total consumed (g/ n)	Mean daily consumption (g/ n)
45	20.99	M	watercress	0.016	0.005	monkey musk	0.037	0.012
21	2.85	F	watercress	0.018	0.006	monkey musk	0.047	0.016
31	6.73	F	watercress	0.030	0.010	monkey musk	0.025	0.008
25	3.4	M	watercress	0.030	0.010	monkey musk	0.021	0.007
33	8.02	F	watercress	0.028	0.009	monkey musk	0.006	0.002
23	3.79	F	monkey musk	0.018	0.006	oxygen weed	0.000	0.000
41	15.88	F	monkey musk	0.019	0.006	oxygen weed	0.004	0.001
28	5.96	M	monkey musk	0.026	0.009	oxygen weed	0.028	0.009
32	8.19	F	monkey musk	0.020	0.007	oxygen weed	0.030	0.010
31	6.99	F	monkey musk	0.031	0.010	oxygen weed	0.008	0.003
32	8.67	F	watercress	0.031	0.010	oxygen weed	0.096	0.032
33	8.29	F	watercress	0.038	0.013	oxygen weed	0.025	0.008
37	10.97	F	watercress	0.053	0.018	oxygen weed	0.036	0.012
25	4.01	M	watercress	0.025	0.008	oxygen weed	0.004	0.001
28	5.71	M	watercress	0.027	0.009	oxygen weed	0.007	0.002
23	3.68	M	mayflies	24	8.000	snails	19	6.333
33	9.03	F	mayflies	25	8.333	snails	25	8.333
29	5.9	M	mayflies	18	6.000	snails	14	4.667
41	17.36	F	mayflies	25	8.333	snails	25	8.333
21	3.01	F	mayflies	25	8.333	snails	12	4

Appendix I

Table 4.8 Total and mean daily consumption of detrital treatments dry weight (g), with kekewai carapace size (OCL), wet weight and sex recorded

OCL (mm)	W/W (g)	Sex	Food Choice 1	Total Consumed (g)	Mean Daily Consumption (g)	Food Choice 2	Total Consumed (g)	Mean Daily Consumption (g)
14	1.59	F	Willow	n c	n c	Pittosporum	0.069	0.0228
34	9.25	M	Willow	0.111	0.037	Pittosporum	0.053	0.0175
44	19.31	M	Willow	0.055	0.018	Pittosporum	0.055	0.0182
22	2.47	M	Willow	0.088	0.029	Pittosporum	0.029	0.0095
17	1.46	F	Broadleaf	0.077	0.026	Willow	0.040	0.0133
21	2.88	M	Broadleaf	0.016	0.005	Willow	0.046	0.0153
35	9.60	F	Broadleaf	0.098	0.033	Willow	0.034	0.0113
19	2.47	M	Broadleaf	0.059	0.020	Willow	0.038	0.0127
18	1.34	M	Pittosporum	n c	n c	Broadleaf	n c	n c
21	2.88	M	Pittosporum	0.039	0.013	Broadleaf	0.019	0.006
34	9.43	F	Pittosporum	0.01	0.003	Broadleaf	0.117	0.039
23	2.86	F	Pittosporum	0.015	0.005	Broadleaf	0.026	0.009